July 19, 1995

Review Study of the U.S. Army Corps of Engineers' Solar Feasibility Methodology

Lindsey Evans

JTI Systems, Inc.

John Anderson, Carl Bennett, Earl Rush

Sandia National Laboratories

Solar Thermal Design Assistance Center

Albuquerque, NM 87185-0703

Review Study of the U.S. Army Corps of Engineers' Solar Feasibility Methodology

Lindsey Evans

JTI Systems, Inc.

John Anderson, Carl Bennett, Earl Rush

Sandia National Laboratories

Solar Thermal Design Assistance Center

Albuquerque, NM 87185-0703

ABSTRACT

Sandia National Laboratories' Solar Thermal Design Assistance Center completed a review study of the U.S. Army's Corps of Engineers' solar thermal system evaluation methodology, which is used to determine the applicability of solar heat systems for Department of the Army facilities. As a result, several recommendations, discussed in this report, have been forwarded to improve the methodology. The recommendations include a new solar economic screening tool and suggested improvements to the U.S. Army Corps of Engineer's design/installation specifications.

This page left intentionally blank.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
CERL	U.S. Army Construction Engineering Research Laboratories
COE	U.S. Army Corps of Engineers
CONUS	continental United States
DOA	Department of the Army
DOD	Department of Defense
FSEC	Florida Solar Energy Center
GSA/FEM	General Services Administration's Federal Energy Management program
M&R	maintenance and repair
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Data Base
SEIA	Solar Energy Industries Association
SNL	Sandia National Laboratories
STDAC	Solar Thermal Design Assistance Center
SOLFEAS	The COE's SOLar FEASibility computer program for assessing potential solar energy projects
SRCC	Solar Rating and Certification Corporation

SECTION 1 Executive Summary

1.1 Introduction

The U.S. Army Corps of Engineers (COE) has recently decided to review their solar evaluation program to determine if their methodology used to evaluate solar systems needs revisions. As a result, the COE contacted the Solar Thermal Design Assistance Center (STDAC) at Sandia National Laboratories (SNL) to request services for reviewing the COE's solar evaluation methods. The STDAC was contracted by the COE through the federal government's Work For Others Program, proposal # 062940426, to critically review and evaluate the COE's solar feasibility and evaluation program.

The COE is mandated by the federal government to evaluate the use of solar energy systems for most Department of Defense (DOD) new building construction. Currently, the COE follows a defined evaluation procedure for assessing the feasibility of solar water heating systems. The purpose of the study described in this report was to perform an independent review of the documents and approach used by the COE for assessing the economic feasibility of active solar water heating systems on U.S. Army installations.

To perform this study, the STDAC reviewed the following:

- the COE's *Active Solar Feasibility Study for the Continental United States,*[1] referred to in this report as the generic solar feasibility study

- the computer program SOLar FEASibility,[2] referred to in this report as SOLFEAS
- the *Section 13600 Solar Water Heating Equipment Specification*.[3]

The SOLFEAS program and the design specification were developed during the 1980s by the U.S. Army Construction Engineering Research Laboratories (CERL) for supporting the COE's solar program. The specification is used in conjunction with the training manual TM5-804-2, *Domestic and Service Water Active Solar Energy Preheat Systems*.[4] The STDAC did not perform a critical review of the training manual under this contract; however, in support of the specification review, the training manual was studied.

This report provides the STDAC's review comments on the COE's methodology for assessing solar feasibility. Recommendations are provided regarding changes to the COE's generic solar feasibility study, and a simple screening process of solar systems is proposed as a replacement to the generic solar feasibility study. Suggested upgrades to the COE's computer code for solar system performance and life-cycle analysis (SOLFEAS) are presented, and a review by the solar industry of the equipment specification used by the COE is provided. The review comments and recommendations were based on Sandia's experience and unbiased technical expertise in solar thermal technology, input from six solar companies from around the United States, and review comments from CERL. An overview of the review of the COE's solar feasibility methodology, discussed in detail in Sections 2 through 5 of this report, follows.

1.2 Generic Solar Feasibility Study

The STDAC performed an assessment of the evaluation process used in the generic solar feasibility study. The objectivity of the criteria used in the generic study for assessing the feasibility of solar systems was evalu-

1. COE-Tulsa. 1990. *Active Solar Feasibility Study for the Continental United States.* November 1990. Prepared by the U.S. Army Engineer District, Tulsa, OK, for the U.S. Army Engineer Division, Southwestern.

2. COE-Ft. Worth and CERL. 1993. *SOLFEAS: The U.S. Army solar feasibility study design tool, Version FY94.* December 1993. Prepared by BLAST Support Office and the U.S. Army Construction Engineering Research Laboratories, Champaign, Illinois.

3. COE. 1990. *Section 13600 Solar Water Heating Equipment Specification.* 1990. U.S. Army Core of Engineers.

4. DOA (Department of the Army). 1992. *Technical Manual: Domestic and Service Water Active Solar Energy Preheat Systems.* February 1992. TM 5-804-2.

ated. Also, the technique the COE uses to evaluate discounted payback was evaluated.

In general, we did not find the generic study to be biased against solar energy. The results of the generic study, used to evaluate the economic feasibility of solar systems, are based on optimal solar conditions, low system construction costs (as determined using the *1990 Means Mechanical Cost Data*[5]), and high fuel costs. These results indicate that solar water heating will not be economically feasible for consideration under most circumstances. We concur that, under most circumstances, solar water heating will not meet the federal government's requirements for a discounted payback of 10 years or less.

However, we believe that the COE should not solely use the results of the generic study for investigation of solar energy systems. The problem with an approach such as the generic study is that potential solar systems can be rejected by simply referring to the study. This approach does not account for niche applications in which a solar system would be cost effective.

To remedy this problem, we have recommended a low-cost approach that uses initial screening guidelines and simple payback analysis. If a project meets certain criteria (e.g., heating costs exceeding $0.065/kWh, environmental externalities that make conventional fuels expensive, financial incentives from local utilities), then the payback analysis is performed, quickly identifying the solar system costs and fuel costs required to meet a payback of 10 years or less. Using the results of the simple payback analysis, the potential of a project can be easily determined.

Payback analysis can be performed using a Microsoft Excel spreadsheet developed by the STDAC that calculates the simple payback of a flat-plate or evacuated-tube collector system. (A 3.5-inch diskette containing this spreadsheet file for Windows personal computers is included in Appendix A of this report.) The calculations for simple payback are based on varying fuel costs and varying system installed costs. Collector performance data used in the spreadsheet calculations were taken from data presented in the *Active Heating Systems Design Manual,*[6] published by the American Society of Heating, Refrigerating, and Air Conditioning Engineers and the Solar Energy Industries Association. Using the spread-

5. Robert Snow Means Co. 1990. *1990 Means Mechanical Cost Data.* RS Means Co. Kinston, Massachusetts.

6. ASRAE and SEIA. 1988. *Active Solar Heating Systems Design Manual.* Document 90003.

sheet as a screening tool for solar hot water systems, an initial economic evaluation can be performed to determine if an application has any potential. The results presented by this spreadsheet will give an indication of the conditions needed for meeting a desired payback. Based on the results of this screening approach, one can then determine if subsequent, more detailed evaluations are warranted.

The STDAC's review of the generic solar feasibility study, along with STDAC's recommended screening procedure and payback analysis approach are discussed in detail in Section 2. A more detailed payback analysis is found in Appendix B.

1.3 SOLFEAS

The COE's generic study was based on a SOLFEAS analysis of solar system performance and life-cycle-cost for solar water heating systems. The STDAC assessed the life-cycle cost results of the SOLFEAS computer code and evaluated the program's functionality. A comparison of SOLFEAS to STDAC's evaluation method of solar systems was performed. Also, SOLFEAS was used to perform a sensitivity analysis of payback to varying system costs and fuel costs.

We have found the SOLFEAS program to be adequate for evaluating solar water heating systems. For similar types of collectors, performance predictions by SOLFEAS were in good agreement with our analyses (within 10% or less).

Nevertheless, there were some important differences between the SOLFEAS program and the STDAC's solar analysis experience. Even though the lowest construction costs per the *1990 Means Mechanical Cost Guide* were used, the SOLFEAS installed system cost estimates were significantly higher than average ($80/ft^2); however, they were not excessive. Maintenance and repair (M&R) cost estimates used by SOLFEAS did seem excessive (4 to 18 times greater than STDAC estimates).

For an initial economic analysis, the installed system cost should reflect the most optimistic costs. If a system is not economically feasible when using low system costs, then it certainly would not be feasible to consider when using higher installed costs. The installed system costs generated by SOLFEAS are in line with the costs the STDAC has seen for solar hot water heating systems, but they are higher than average. To fine-tune an economic analysis of a solar hot water heating system, we recommend that the installed system costs be based on cost estimates provided by solar contractors, or an average installed cost could be used if multiple cost estimates are known.

The STDAC's review of the SOLFEAS computer code is provided in Section 3; in addition, SOLFEAS's capabilities for performing payback analysis are discussed in Section 2. A comparison of SOLFEAS with the STDAC's solar evaluation method is provided in Appendix C.

1.4 Equipment Specification

The solar equipment specification was evaluated with respect to its intent and applicability to solar water heating. The specification was also evaluated for completeness and the design requirements were assessed in regard to their relevance to the design of solar water heating systems. To help evaluate the equipment specification, six solar firms were hired to review the specification. For a historical perspective regarding the specification, the STDAC contacted CERL.

For the type of solar systems that are considered by the *Section 13600 Solar Water Heating Equipment Specification*, we did find the specification's requirements to be appropriate and not excessive. However feel that the specification's collector requirements could be relaxed to allow more flexibility in the design of the collector. We recommend that the COE's specification should stay with flat-plate collectors, but that the specification should assure that the collectors meet a minimum, certifiable level of performance.

In addition, it is not clear if the COE has a formal method for evaluating other solar energy systems that are not considered by the current specification. Limiting the specification to flat-plate systems may remove from consideration other types of solar water heating systems such as packaged units, evacuated-tube systems, and large parabolic-trough systems. We therefore recommend that the COE have a mechanism for evaluating these alternative solar energy systems. Such a mechanism would provide some flexibility in the COE's overall solar energy evaluation program.

The review of the equipment specification is discussed in Section 4. A comprehensive summary of the review by industry is provided in Appendix D, and a recommended performance specification for solar thermal heating systems is included in Appendix E. Finally, Section 5 presents the STDAC's overall conclusions and recommendations in detail.

This page left intentionally blank.

SECTION 2

Generic Solar Feasibility Study

The COE's rationale for developing the generic solar feasibility study[1] was based on a need to reduce the costs of evaluating solar energy projects, while still meeting the federal requirement for evaluating solar energy systems for new building construction. Studies of solar water heating systems installed on Army installations revealed that in most cases these systems were not economically feasible. Yet, before the generic solar study approach was adopted, the COE was spending on an average $5000 dollars per project to have a solar feasibility study performed. Consequently, the generic study was developed as an evaluation report that analyzed the economic feasibility of solar water heating systems. This report was based on the premise that if solar water heating systems were not cost effective for a theoretical site using the most favorable solar conditions and costs, then a solar water heating system using actual site conditions would not be economically feasible. Also, the COE concluded that if solar water heating was not feasible for a system supplying a year-round load, then solar cooling and space heating would be even less feasible.

The results of the generic study indicated that, for the continental U.S. (CONUS), the discounted payback for a solar water heating system was less than 25 years if the fuel being displaced was electricity. Also, the

1. COE-Tulsa. 1990. *Active Solar Feasibility Study for the Continental United States.* November 1990. Prepared by the U.S. Army Engineer District, Tulsa, OK, for the U.S. Army Engineer Division, Southwestern.

generic study determined that only for Department of Energy Region 6 (Texas, Oklahoma, Arkansas, and Louisiana) was it economically feasible to consider solar water heating, and only if solar was displacing electricity. Based on the results of the generic solar study, the general conclusion was that the majority of the solar feasibility studies being performed for the COE were unnecessary and could not be justified. The COE has decided to use the results of the generic study for initial economic evaluation of solar energy systems.

We agree with the COE's viewpoint regarding the economic feasibility of solar heating and cooling systems. In the U.S., seasonal usage of solar energy systems have yet to be proven cost effective. It is difficult for solar systems to be economically feasible for year round usage, let alone for seasonal usage. Given the requirement that a solar hot water system needs to meet a discounted payback of 10 years or less, then domestic solar water heating will not be economically feasible unless conventional fuel prices are high (greater than $0.065/kWh). Considering current fossil fuel prices and the expected low escalation in fuel costs, solar water heating systems in most cases will not be economically feasible to use. Thus, at this time, the COE is justified in considering only solar hot water systems for buildings with year-round usage.

However, in areas where fuel costs are high or in cases where solar is competing against electricity, solar water heating may be economically feasible. It is for these niche applications that solar hot water systems may have a chance of meeting the payback requirement. In addition, there may exist certain situations where solar process heat for space heating and cooling also are feasible. As performance and costs of these systems continue to improve and economies of scale drive down prices of solar equipment, more niche applications for space cooling and heating in all likelihood will become feasible. As is explained below, it is therefore important to have a screening tool that does not dismiss these niche applications a priori.

2.1 Screening Methodology

The objective of a screening tool is to identify potential solar water heating projects in a manner that is quick, straightforward, and cost-effective. The following is a guideline that can be used to screen potential solar water heating projects. This guideline is based on screening criteria developed by the National Renewable Energy Laboratory (NREL) for the General Services Administration's Federal Energy Management (GSA/FEM) Solar Heat program.

Acceptance Criteria. If one or more of the following conditions are met, then solar water heating has the potential of being feasible:

- Water heating (regardless of hot water usage rate) using conventional fuel costs \$0.065/kWh[2] or greater.
- Year-round usage of hot water is at a rate of 15 gallons/person/day or greater (for at least 6 days a week) and conventional fuel costs are \$0.045/kWh[2] or greater.
- Site/facility is in an area where environmental issues, such as air-quality non-attainment, provide an incentive for using renewable energy projects over natural gas or propane.
- Payback periods exceeding 10 years are acceptable.

Rejection Criteria. If one or several of the following conditions are met, then solar water heating is not a promising project:

- There is no space to place the solar collectors.
- The solar collectors would be viewed as architecturally/aesthetically unacceptable.
- A site/facility layout makes it impossible to place the solar collectors in an orientation facing south (or near south).

Additional Considerations. There are other conditions that help make solar water heating potentially more promising:

- There is a "champion" for using solar at the facility/site.
- The facility could serve as a "Showcase Facility" as defined in President Clinton's "Energy and Water Conservation at Federal Agencies" Executive Order 59 FR 11463.[3]
- Financial incentives for solar are being offered by the local utility.
- Funds or grants are available specifically for renewable energy projects.

2.2 Payback Analysis

If the initial screening process indicates that a solar water heating project has potential, then a simple payback analysis should be performed. Based

2. Boiler efficiency, which is factored in for evaluation of systems using natural gas but not for systems using electric heating, is not reflected in these costs. For example, natural gas costing \$5/MMBtu with a boiler efficiency of 60% has a resulting conventional fuel cost of \$8.33/MMBtu (\$0.03/kWh).

3. President of the U.S. 1994. *Energy Efficiency and Water Conservation at Federal Facilities.* Executive Order 12902, March 8, 1994. 59 FR 11463, Vol. 59, No. 047.

on the results of the simple payback study, one can determine if an in-depth solar feasibility study is warranted.

The generic solar study was set up on the premise that the economic feasibility of solar water heating is a function of the cost of the fuel being displaced. While fuel cost is one important element for performing an economic evaluation, installed cost of the solar system is another element that must be considered when performing payback analysis. Fuel prices are reasonably known with small variations, but solar system installed costs can vary considerably. Thus, another approach to the solar feasibility question is to look at the payback for varying both system costs *and* fuel costs.

2.2.1 Example Fuel/System Cost Payback Analysis Using SOLFEAS

The following is an example of a sensitivity analysis of payback period for varying fuel costs and varying system costs of a solar water heating system used in Albuquerque, New Mexico. The load was based on the conditions given in the generic study for a 500-man barracks with a dining facility. The daily hot water load was set at 6.831 MMBtu/day. Using SOLFEAS thermal analysis results, a solar system that would meet 50% of the hot water load was used. Results of this example are presented in Table 2-1.

SOLFEAS estimated the system costs at $81 per square foot of collector, and natural gas cost at $3.93 per MMBtu. Based on SOLFEAS initial analysis, the estimated payback was greater than 30 years. The example indicated that, at a fuel cost similar to SOLFEAS estimate ($4 per MMBtu), the installed cost would need to be less than $21/ft^2 to meet a 10-year payback. Using the SOLFEAS installed system cost estimate of $81/ft^2, the natural gas cost would need to be $8 per MMBtu or greater before payback periods of less than 25 years could be realized.

Using $40/ft^2 for installed costs of a flat-plate system — a low but not unreasonable cost estimate — the natural gas prices would need to exceed $7 per MMBtu before consideration of a solar hot water system would be warranted. Performing a sensitivity analysis similar to this example would help in identifying the range of system costs and fuel prices needed to achieve a reasonable payback for a solar water heating system.

Table 2-1 Payback sensitivity analysis using SOLFEAS

	Collector Cost								
Fuel Cost	$21/ ft²	$24/ ft²	$32/ ft²	$40/ ft²	$48/ ft²	$56/ ft²	$64/ ft²	$72/ ft²	$81/ ft²
$2/ MMBtu	28.3	>30	>30	>30	>30	>30	>30	>30	>30
$3/ MMBtu	15.9	19	27.9	>30	>30	>30	>30	>30	>30
$4/ MMBtu	10.9	13	18.5	24.5	>30	>30	>30	>30	>30
$5/ MMBtu	8.2	9.8	13.8	18	22.6	27.5	>30	>30	>30
$6/ MMBtu	6.6	7.8	10.9	14.2	17.6	21.4	25.3	29.6	>30
$7/ MMBtu	5.5	6.5	9	11.7	14.5	17.4	20.5	23.8	>30
$8/ MMBtu	4.7	5.5	7.7	9.9	12.2	14.6	17.2	19.9	23.1

However, using SOLFEAS in its present form and manually inputting the fuel and system cost information is very time consuming. SOLFEAS generates system costs based on two second-order cost curves, and the information used for system costs is derived from *1990 Means Mechanical Cost Data.*[4] Making changes to SOLFEAS cost analysis is not a straightforward process. A user must enter changes to the cost-curve parameters to get revised system costs, and then iterate on the cost-curve parameters until the desired system cost is achieved. Because of the rigid structure of the system cost-curve routine used in the SOLFEAS program, it would not be practical to use the current SOLFEAS setup to perform a two-variable sensitivity analysis. However, the SOLFEAS program could be amended to allow the user to evaluate the payback for a range of fuel costs and system costs. This would require adding the necessary code that would vary costs automatically.

2.2.2 Example Simple Payback Analysis of Fuel and System Costs

An alternative to using SOLFEAS for performing a sensitivity analysis would be to use the STDAC's simple payback approach. In a simple pay-

4. Robert Snow Means Co. 1990. *1990 Means Mechanical Cost Data.* RS Means Co. Kinston, Massachusetts

back analysis all that is required is information on the solar collector's annual performance for the site of interest. The simple payback can then be calculated using the collector performance information, along with system cost estimates and fuel cost estimates. The following equation describes how simple payback is calculated:

$$\text{PAYBACK} = \frac{\text{INSTALLED SYSTEM COST (\$)}}{\left[\dfrac{\text{SOLAR ENERGY DELIVERED (MMBtu/year))}}{\text{BOILER EFFICIENCY}}\right] \times \text{FUEL COST (\$/MMBtu)}}$$

Note that in the simple payback analysis the hot water load requirements, material costs, maintenance costs, construction costs, fuel escalation rates, and discount rate are not required. All that is needed is collector performance information for estimating the amount of conventional fuel being displaced. The payback can then be evaluated as a function of varying fuel costs and system costs. The user decides on the range of fuel and system costs to use in the analysis.

Simple payback analysis can be used as a tool for screening solar water heating systems. The analysis is easy to perform and can provide an estimate on what the installed system costs and fuel costs need to be for meeting a specified payback. If the indicated costs are reasonable for meeting the desired payback, then a complete feasibility analysis would be performed.

Results of an example simple payback analysis of a solar hot water heating for Albuquerque, New Mexico, are presented in Table 2-2. The flat-plate collector thermal performance was reported as 0.308 MMBtu/ft^2/yr. This collector performance data was taken from the ASHRAE *Active Solar Heating Design Manual.*[5] For this analysis, the installed system costs were varied from $20 to $100 per square foot of collector, and natural gas prices were varied from $2/MMBtu to $8/MMBtu. A fuel conversion (boiler) efficiency of 65% was used for this analysis.

For the current natural gas price in Albuquerque ($4/MMBtu), the results indicate that it would not be feasible to consider a solar water heating system unless the system can be installed at $20/ft^2 or less. Usually installed costs for flat-plate system will be greater than $20/ft^2. Thus, if a

5. ASRAE and SEIA (American Society of Heating, Refrigeration, and Air Conditioning Engineers and Solar Energy Industries Association). 1988. *Active Solar Heating Systems Design Manual.* Document 90003.

10-year payback is required, it would not be justified to consider a solar water heating system.

If simple payback analysis gives an indication that a reasonable payback is possible for valid fuel costs and system costs, then an in-depth study should be performed. Information concerning solar feasibility studies can be obtained from the ASHRAE *Active Solar Heating System Design Manual.* This manual is an excellent reference not only for performing solar feasibility studies, but also provides details in the design of active solar systems.

Table 2-2 Simple payback analysis for a solar hot water heating system used in Albuquerque, New Mexico

Fuel Cost	Collector Cost $20/ ft^2	$30/ ft^2	$40/ ft^2	$50/ ft^2	$60/ ft^2	$70/ ft^2	$80/ ft^2	$90/ ft^2	$100/ ft^2
$2/ MMBtu	21	32	42	53	63	74	84	95	106
$3/ MMBtu	14	21	28	35	42	49	56	63	70
$4/ MMBtu	11	16	21	26	32	37	42	47	53
$5/ MMBtu	8	13	17	21	25	30	34	38	42
$6/ MMBtu	7	11	14	18	21	25	28	32	35
$7/ MMBtu	6	9	12	15	18	21	24	27	30
$8/ MMBtu	5	8	11	13	16	18	21	24	26

2.2.3 Resources for Payback Analysis

The payback study should use fuel costs for the area of interest, and collector performance values can be obtained from the ASHRAE *Active Solar Heating Systems Design Manual*, from the Solar Rating and Certification Corporation (SRCC, 777 North Capitol Street, Washington, D.C. 20002, 202-383-2570), or from thermal analysis codes such as SOLFEAS. ASHRAE's *Active Solar Heating Systems Design Manual* contains a listing of flat-plate collector performance data for good and average collectors used in various sites within the U.S. Also, provided with this report is a Microsoft Excel Version 5 file (on disk; see Appendix A) that can be used to calculate the simple payback for either flat-plate or evacuated-tube collectors used in a water heating system.

Contained in Appendix B is a review of a basic solar feasibility determination procedure. (An article explaining this procedure is scheduled to be published in the *ASHRAE Journal* in the Fall of 1995.[6]) This procedure incorporates NREL's *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.*[7] This manual contains average daily values for incident direct-beam radiation for concentrating collectors, and global radiation values for non-concentrating collectors facing south at various tilt angles.

By going through the procedure presented in Appendix B, one will gain experience in using solar collector performance data, solar radiation data, and estimating solar array requirements. Also, the procedure points out that solar system costs should be based on current prices provided by solar system manufacturers or solar system installers. By following this type of procedure an individual will eventually become familiar with the issues pertaining to solar water heating, and a forthright solar feasibility analysis will be accomplished.

2.3 Recommendations

As a revision to the COE's current feasibility methodology, the following recommendations should be considered:

- Include a screening guideline similar to that presented in Section 2.1.1.
- Use simple payback analysis following either the STDAC approach or modified version of SOLFEAS for further screening of solar water heating projects that make it through the initial screening step described in Section 2.1.1.

Incorporating these changes will help the COE in establishing a direct method that requires a minimum level of effort — and cost — for evaluating a solar water heating project. Also, by spending some effort in the initial screening process, the potential of finding a feasible project is increased. Using this type of methodology can provide a reasonable and unbiased analysis of solar system feasibility.

6. Bennett, C.W. 1995. "Solar-heat Technology — A Primer." Accepted for Publication in the *ASHRAE Journal*. Scheduled print date: September 1995.

7. NREL. 1994. *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* NREL/TP-463-5607, DE93018229. Printed April 1994. National Renewable Energy Laboratory: Golden, Colorado.

SECTION 3 SOLFEAS

The COE's SOLar FEASibility (SOLFEAS) program[1] is unique in that it combines solar system thermal performance analysis with life-cycle-cost analysis. In its present form, SOLFEAS is an adequate program for performing economic analysis of solar water heating systems. However, if the COE intends on using SOLFEAS as the primary feasibility analysis tool, then a few changes to the program should be considered. The changes, discussed in this section, pertain to the following:

- user input requirements
- types of solar systems that can undergo performance analysis
- analysis of system costs and maintenance and repair (M&R) costs
- solar weather data.

These changes should be easy to incorporate and would make SOLFEAS a more versatile program that would provide the users with the ability to vary input parameters.

3.1 User Input Requirements

Generally, the input requirements for SOLFEAS are straightforward, and only a minimal amount of information is required to run the program.

1. COE-Ft. Worth and CERL. 1993. *SOLFEAS: The U.S. Army solar feasibility study design tool,* Version FY94. December 1993. Prepared by BLAST Support Office and the U.S. Army Construction Engineering Research Laboratories, Champaign, Illinois.

Also, the user only needs to have a limited understanding of the input parameters to run SOLFEAS.

However, in those cases where a solar water heating project appears to be potentially feasible, the user may want to adjust the input parameters. The input parameters that are of primary interest include the solar system installed costs, maintenance costs, and fuel costs. Fuel costs are reasonably understood, but the user may be interested in knowing what the effect of varying fuel costs has on the analysis. Solar system costs and maintenance costs are not easily quantified and the user may wish to vary these costs to determine the sensitivity of the economic analysis to these cost changes.

3.2 SOLFEAS-STDAC Comparison Results

A comparison study of SOLFEAS to the STDAC's solar feasibility method is presented in Appendix C. As the results of the comparison show, the thermal performance analysis results of each method were within 10% of each other. The approach that the STDAC uses for estimating system performance is to determine the available monthly solar radiation at the site of interest, and then assume an overall system efficiency. SOLFEAS uses a universal performance equation for estimating system performance. Based on our experience using SOLFEAS, the performance curve used in the program provides reasonable estimates for system performance.

3.3 Solar Systems Considered for Performance Analysis

The only limitation of the SOLFEAS solar system thermal performance analysis is that it is based on flat-plate systems. The other solar heat technologies that are used for water heating (evacuated-tube and parabolic-trough systems) are not considered in the SOLFEAS analysis. The COE may want to consider making a revision to SOLFEAS to allow for the evaluation of evacuated-tube and parabolic-trough systems. Such a revision would add to the flexibility of the system.

An approach to adjusting the thermal performance results of SOLFEAS is to allow the user to manipulate overall solar system performance. This could be accomplished by taking the available solar radiation for the site of interest, and then multiplying this value by the overall system efficiency. The efficiency number can be either a default value that SOLFEAS calculates, such as what is currently done, or the user can input efficiency values. By having this capability built into the program, the thermal performance results would not be locked to just those of flat-plate systems. Also, this capability would allow a user to determine if overall system performance has a significant impact on the economics.

The following guidelines could be used as estimates for system efficiency values:

- For trough technology, use an overall efficiency of 50% conversion of the direct-beam solar radiation for May to September, and 40% for the remainder of the year.
- For evacuated-tube collectors, use an overall efficiency of 50 to 60% conversion of the total horizontal radiation.
- For a flat-plate collector, use 45% conversion efficiency of total horizontal radiation for the months of May to September and 35% for the remainder of the year.

The above values are rough estimates on overall system efficiency for the various solar heat technologies, and will provide a reasonable approximation to true system performance. Incorporating this technique into the SOLFEAS program will add to the versatility of the program. The drawback to this technique is, if the user inputs an unrealistic value for efficiency (either high or low), the results could be misleading. However, varying the overall system efficiency will provide information on the influence that system performance has on the economics. For example, in the comparison study, (Appendix C), the performance predicted by SOLFEAS was 0.290 MMBtu/ft^2 and the performance estimated by our method was 0.323 MMBtu/ft^2, but neither analysis showed the system to be economically feasible. Thus, one could conclude that even if the performance was increased from 0.290 MMBtu/ft^2 to 0.323 MMBtu/ft^2 (11% increase), the system would still not be economically feasible.

3.4 System/Maintenance and Repair Cost Analysis

The comparison study of our method to SOLFEAS's showed a significant difference in system costs and maintenance costs. Even though the lowest regional construction costs per the *1990 Means Mechanical Cost Guide*[2] were used by SOLFEAS for the generic solar feasibility study, the SOLFEAS program predicted costs that were about 80% greater than STDAC cost estimates. SOLFEAS' maintenance cost estimates were markedly higher (4 to 18 times higher) than our maintenance estimates.

2. Robert Snow Means Co. 1990. *1990 Means Mechanical Cost Data.* RS Means Co. Kinston, Massachusetts

3.4.1 System Costs

A possible reason for the high system costs could be because SOLFEAS calculates system cost based on a standard solar system as described in the training manual TM5-804-2,[3] and not on quoted cost estimates. The STDAC, on the other hand, tries to use system cost estimates that are based on costs provided by installers and manufacturers of solar systems.

Although the SOLFEAS system cost estimates are not unrealistically high, they do appear to always be above the average range. When using SOLFEAS, we determined that in every case the system costs were significantly above average. These high predicted costs could be misleading. We therefore recommend that, whenever SOLFEAS is used in a feasibility study, analysis should be carried out for at least two different system cost estimates. One system cost estimate should be calculated by the program. The other should be based on a quoted cost or at least a cost lower than SOLFEAS's cost. By using two cost estimates in the analysis, the user will be able to determine if system cost is significantly influencing the results.

Arriving at an accurate system cost estimate for a solar hot water heating system is difficult and depends on many parameters. We have found that for solar hot water systems similar in size to the standard system described in TM5-804-2, the installed costs range anywhere between $\$40/ft^2$ to $\$100/ft^2$. Also, system costs are very dependent on the site installation requirements. In ASHRAE's *Active Solar Heating Systems Design Manual*,[4] costs given in 1987 dollars for hot water heating ranged from $\$40/ft^2$ to $\$80/ft^2$ for flat-plate systems and $\$40/ft^2$ to $\$95/ft^2$ for evacuated-tube systems. For analyses performed by the STDAC, the installed system costs generated by SOLFEAS ranged from $\$80/ft^2$ to over $\$100/ft^2$. These values are within the ranges used for estimating system cost, but are well above average.

If a cost estimate cannot be provided, then cost information should be based on the most recent information. From our discussion with Larry Lister of CERL, current data for labor and materials costs used in SOLFEAS are for 1989 and need to be updated. The COE may want to consider having this cost data updated.

3. DOA (Department of the Army). 1992. *Technical Manual: Domestic and Service Water Active Solar Energy Preheat Systems.* February 1992. TM 5-804-2.

4. ASRAE and SEIA (American Society of Heating, Refrigeration, and Air Conditioning Engineers and Solar Energy Industries Association). 1988. *Active Solar Heating Systems Design Manual.* Document 90003.

3.4.2 Maintenance and Repair Costs

Maintenance and repair costs for flat-plate systems are not well documented; however, the COE may have historical records for their solar system maintenance costs. SOLFEAS bases M&R costs on a percent of the system's installed cost. The STDAC's experience has been with trough systems (3000 ft^2 or greater), where the M&R costs per square foot of collector are reported to be $0.25 per square foot per year. Trough systems have more moving parts than flat-plate systems, and the controls are more complex; therefore, the STDAC would anticipate the M&R cost to be greater for a trough system than for a comparably sized flat-plate system.

3.5 Solar Weather Data

The current version of SOLFEAS uses the SOLMET data base for solar radiation input to the program. SOLMET has now been replaced with the new National Solar Radiation Data Base (NSRDB).[5] This new data base covers a longer and more recent period (1961-1990) than SOLMET (1952-1975). The NSRDB uses improved measurements and an improved model for estimating solar radiation. The rationale for a new data base was based on studies that found a great deal of variations in the apparent quality of the SOLMET data.[6] This was based on differences in the predicted values for mean global horizontal radiation and direct normal radiation from SOLMET to measured values. Differences between SOLMET and measured radiation were as great as 50%. If there is considerable demand for SOLFEAS, it is recommended that the program be upgraded to use the new data base NSRDB. However, if the use of SOLFEAS is minimal, it is probably not practical to make this change.

3.6 Recommendations

The current form of SOLFEAS is adequate to perform solar feasibility studies. Incorporating the above changes into the program will add flexibility in the COE's solar feasibility methodology. However, if the COE believes that demand for SOLFEAS is limited, then it would not behoove the COE to make any program changes to SOLFEAS. Additionally, it would be to the COE's best interest to have someone within the COE

5. NREL. 1992 and 1995. *National Solar Radiation Data Base (1961-1990)*. Prepared by the National Renewable Energy Laboratory: Golden, Colorado. (Volume 1, *User's Manual*, printed September 1992, distributed by the National Climatic Data Center, Federal Building, Asheville, North Carolina 28801; Volume 2, *Final Technical Report*, printed January 1995).

6. Marion, W. and D. Myers. 1992. *A Comparison of Data from SOLMET/ERSATZ and the National Solar Radiation Data Base*. NREL/TP-463-5118, DE93000018. Printed November 1992. National Renewable Energy Laboratory: Golden, Colorado.

who could be the resident solar expert. This individual would be the main source who would assist in using the program and could make the determination on when an inadequate or unrealistic input to the program has been used. Having this capability will help strengthen the COE's solar efforts.

SECTION 4

Section 13600 Specification

The STDAC, with the assistance of six solar firms and the U.S. Army Construction Engineering Research Laboratories, evaluated the intent and applicability of the COE's *Section 13600 Solar Water Heating Equipment Specification* to solar water heating. This section discusses the results of the evaluation.

4.1 Scope of Specification

The solar water heating equipment specification used by the COE is complete but does not clearly indicate which solar water heating systems it covers. Based on discussions with Larry Lister of the U.S. Army Construction Engineering Research Laboratories (CERL), the specification is for an uninhibited glycol, closed-loop, flat-plate array of approximately 1000 to 3000 square feet. It is important to provide this description of the standard solar energy system in the general section of the specification. The training manual TM5-804-2[1] discusses the standard solar energy system in Sections 1-2, 3-2, and 3-3, but does not clearly indicate the system size. The manual does mention the maximum collector size of 3000 square feet but does not mention a minimum size.

We agree with the COE's goal of standardizing their solar energy installations. However, this goal, because it is achieved by limiting applica-

1. DOA (Department of the Army). 1992. *Technical Manual: Domestic and Service Water Active Solar Energy Preheat Systems.* February 1992. TM 5-804-2.

tions to flat-plate systems, eliminates from consideration other types of solar water heating systems such as packaged units, evacuated-tube systems, and large parabolic-trough systems. It is not clear if the COE has a formal method for evaluating other solar energy systems that are not considered by the current specification. It would be appropriate for the COE to have a mechanism for evaluating these alternative solar energy systems. Such a mechanism would provide some flexibility in the COE's overall solar energy evaluation program.

Using closed-loop systems for solar hot water heating as the standard solar system is based on CERL's bad experiences (freezing and other system failures) with drainback and open-loop systems, and CERL's preference to the closed-loop glycol systems. Considering the intended limitations of the specification, we concur with CERL's viewpoint regarding the need for using closed-loop systems. Thus, at this time, it is probably in the COE's best interest to continue with this philosophy. In most cases flat-plate collectors will be the collector of choice for service-water heating applications.

However, evacuated-tube collectors and parabolic-trough collectors are also currently being used in service water heating systems. If required, the STDAC can assist the COE in developing a program that could be used to evaluate these other types of solar energy systems.

4.1.1 Evacuated-Tube Collectors

The evacuated-tube collectors that are available today are reliable, and are more efficient than flat-plate collectors. Although evacuated-tube collectors are used in service water heating, they are also good candidates for higher temperature water heating applications, such as solar absorption and desiccant cooling. Since evacuated-tube collectors that are currently available are reliable, they are a viable technology to consider for service water heating, and the COE may wish to reevaluate their position against the use of evacuated-tube collectors.

We suggest that the COE evaluate evacuated-tube system and parabolic-trough system applications on a case-by-case bases. Since at this time few of these systems are being installed, developing specifications for these systems may not be warranted. The STDAC can assist the COE in evaluating potential projects in which evacuated-tube collectors could be used.

4.1.2 Parabolic-Trough Collectors

In some water heating applications it is appropriate to consider concentrating parabolic-trough collectors since large trough systems are often more cost effective than comparable flat-plate systems. An example of a parabolic-trough system used for water heating is a 7800 ft^2 trough system built and installed by Industrial Solar Technology at the Adams County Detention Facility in Brighton, Colorado. Based on our discussions with Larry Lister of the CERL, systems of this size are not considered for use on Army installations. However, even though this particular system is larger than the standard system that the COE considers for service water heating, it does show that the trough technology can be applied for service water heating.

To date, trough systems that have been applied to service water heating have been financed by third parties. If the COE wants to consider larger service hot water systems, third party financing (e.g., energy service contracts) may be an avenue to investigate.

4.2 Designer/Installer Expertise

An area that is not addressed by the specification is solar system experience requirements for designers and installers. Few firms around the country have extensive experience in the design and installation of solar water heating systems, and thus, many of the problems associated with past solar systems can be attributed to inappropriate design or improper installation. Today, many state energy offices that are investing in solar heating systems are starting to require certified solar designers and installers. To meet this requirement, training workshops are being set up to help companies become knowledgeable in solar system design and installation. At a minimum, the COE should consider adding to their solar energy program a requirement that the designers and installers meet some level of expertise in the commercial solar water heating area. Even though this may limit the number of companies that can be contracted by the COE, it does help in reducing problems with inappropriate design or improper installation of solar water heating systems.

4.3 Results of Industry's Review

Six solar firms were hired by the STDAC to review the Section 13600 Specification. The reviewers consisted of parabolic trough manufacturers and installers, solar system installation and repair contractors, and flat-plate collector manufacturers. To ensure candor, the reviewers' request to not be identified by name was honored. An overview of the results of this review follows. Appendix D of this report contains the text of industry's final review of the specification and the STDAC's responses to industry's comments.

In general, the main concerns of industry regarding the specification are:

1. The specification is strictly for large, flat-plate, closed-loop solar water heating systems; other solar heat systems are not considered.
2. Balancing-valve and system-balancing requirements seem excessive.
3. Certification of collectors such as Solar Rating and Certification Corporation (SRCC) or Florida Solar Energy Center (FSEC) rating should be required for flat-plate collectors.
4. The collector warranty requirement of 10 years is excessive and should be in line with other water heating equipment.

Industry's concerns regarding the excessive requirements for flow balancing valves is probably due to a misunderstanding by industry of the standard system requirement (closed-loop, 1000- to 3000-ft^2 systems). The specification covers systems that consist of multiple banks of collectors, therefore the specification agrees with industry's comments. The industry feels that requiring balancing valves on "passive" flow-balanced piping is an overkill and increases the system cost. As one reviewer commented, "balancing valves are a good idea on systems with multiple banks of collectors, but silly on small systems." In view of the past problems with unbalanced flow, balancing valves are a reasonable requirement for multiple banks of collectors. Thus, the specification needs to specify the minimum number of banks before requiring balancing valves.

All reviewers agree that at a minimum an SRCC or FSEC performance certification should be required for the solar collector. Requiring an approved certification is beneficial since collector performance is verified and documented by an independent testing agency. However, an independent rating such as the SRCC will not guarantee overall collector quality.

The industry feels they are being pushed into excessively long warranties. The STDAC does believe the 10 year warranty requirement for the solar collectors be should be reduced. However, we feel that the manufacturers of solar collectors should supply warranties that are in-line with similar types of equipment.

4.4 Cross References for Specification

Some parts of the specification that the industry reviewers commented on were due to uncertainty with a requirement. Various sections of TM5-804-2 Training Manual and notes in the *Guide Specification for Military*

Construction[2] (a companion document to Specification 13600) provide explanations and clarifications on requirements called out in the specification. For example, the specification considers only closed-loop flat-plate systems; however, the training manual and the guide specification do acknowledge that direct circulation systems are also acceptable where no freezing occurs (see Section 3-2(b) in training manual and Note B in guide specification). The STDAC realizes that the training manual and the guide specification notes are meant to be used by the designers and contractors; however, at times only the Section 13600 will be critically reviewed.

We therefore recommend that cross-reference information similar to that contained in Table 4-1 be incorporated into Specification 13600. This table cross-references items in the specification with various sections of the training manual TM5-804-2 and the guide specification notes. To help in clarifying the design requirements of Section 13600, the items presented in Table 4-1 should be used within the appropriate sections of the specification.

Table 4-1 Cross references to the training manual TM5-804-2 and specification notes that can help clarify the specification requirements

Section 13600 Specification	Guide Specification	TM5-804 Training Manual
1.2 System Description Considers only closed-loop flat-plate systems.	Note B Allows direct circulation systems where freezing temperatures do not occur.	Sections 1-2, 3-2, 3-3 Commercial-scale systems (instead of "packaged" residential) specified. Also allows direct circulation systems. Provides guidelines for choosing which system (closed loop or direct) is appropriate.
1.3 Drawing Submittals Lists the types of drawing required.	Note C Clarifies that drawings should indicate design methodology used to assure that equipment shown in detailed drawings is properly sized.	Appendix D Provides comprehensive checklist on which drawings should be included.

2. COE. 1990. *Guide Specification for Military Construction*. September 1990. CEGS-13600.

Table 4-1 Cross references to the training manual TM5-804-2 and specification notes that can help clarify the specification requirements

Section 13600 Specification	Guide Specification	TM5-804 Training Manual
2.2 & 2.5.2 Piping Provides specifications for components of piping system, including pressure/ temperature relief valves, calibrating balancing valves, reverse-return requirements, and pressure relief design.	Notes J&R Clarifies reverse-return requirements and reiterates need for calibrated balancing valves.	Section 4-2 Part 2b and Section 4-4 Part 3 Provides additional information on flow balancing, reverse return piping layout, and array layout and piping schematic; also provides guidelines on sizing of piping.
2.2.7&8 Valves Provides specifications for bronze gate, globe, angle, check, and ball valves.	Note D Clarifies that spring-loaded ("non-slam") check valves are preferred and should be used instead of metal-to-metal lift check valves whenever practical.	Section 4-4 Part 5 (a, b, c, d) Provides additional guidance on use of isolation valves, thumb valves, drain valves, and check valves.
2.2.9 Relief Valves Specifies pressure relief valves for collector and temperature-pressure relief valves for solar storage tank.	Note E Specifies that relief valves located at the low points in the system (usually expansion tank) should open first.	Section 4-4 Part 5(e, f) Provides more guidance on pressure relief and temperature-pressure relief valves.
2.2.10 Balancing Valves Sets requirements for calibrated balancing valves.	Note R Reiterates need for calibrated balancing valves.	Section 4-2 Part b(2) Requires that "manually calibrated balancing valves be included on the outlet of each bank to adjust for any flow imbalances which may occur after construction."
2.2.11 Air Vents Provides pressure, material, and fabrication specifications for air vents.		Section 4-4 Part 5(g) States where air vents should be placed and that automatic air vents with air separators should not be used.
2.4 Collector Subsystem Specifies that collectors should be flat plate, liquid, internally manifolded; provides specifications for the following collector subsystem components: absorber plate and flow tubes, cover glazing, insulation, casing, and mounting/assembly hardware. Also requires a 10-year warranty and thermal efficiency information.	Note F Requires that the designer's drawings describe the collector "as thoroughly as possible" and requires values on drawings for number of collectors, gross area and net aperture area, height/ width, fluid volume, filled weight, warranty period, recommended flow rate, and pressure drop at recommended flow rate.	Section 4-2(a) and Section E-4 Provides guidance on collector construction (absorber construction and components, absorber surface, collector manifold, collector glazings, insulation) and guidance on collector selection. Explains solar collector operation, collector types, collector efficiency and performance.

Table 4-1 Cross references to the training manual TM5-804-2 and specification notes that can help clarify the specification requirements

Section 13600 Specification	Guide Specification	TM5-804 Training Manual
2.5.1 Absorber Area Specifies minimum total array aperture area, size of banks, array orientation, shading from other collectors, and minimum spacing.	Notes H&I Provides guidance on maximum number of collectors per bank. Imposes requirements on minimum array aperture area (should correspond to highest LCC as calculated by SOLFEAS); requires the following information written on drawings: SOLFEAS result for minimum array size, total installed array size, bank size and number of banks, minimum row spacing, array orientation with respect to true south.	Section 3-4(a) Provides guidance on collector array size, tilt angle and azimuth angle, grouping, minimum row spacing, layout, and support structure.
2.5.3 Collector Supports States collector support requirements (material, tilt angle, load tolerance, and access).	Note K Additional guidance on collector supports specifications. Identifies wind as most critical load requirement.	Section E-4(d) Additional guidance on collector supports specifications. States preference for roof-mounted structures over ground-mounted structures.
2.6 Storage Tank States that storage tank must conform to specifications for hot water storage tanks, that R value for insulation should be not less than 30, that tank penetrations should be factory installed and designed to not allow corrosion.	Note L Specifies storage tank volume as a function of collector area. Specifies the following information on drawings: volume information, R value of insulation, type of lining.	Section 4-3(a, b, c) Provides guidance on storage tank construction, tank sizing, and flow rate.
2.7.1 Heat Exchanger Specifies heat exchanger construction, testing, design pressure, hot-side exit temperature, and maximum operating temperature.	Note M Recommends multiplate heat exchangers over shell-and-tube heat exchangers; specifies that flow rate should be 1.25 times that on the collector side. Specifies the following information on drawings: heat exchanger type and materials, flow rates, and heat transfer area.	Section 4-4 Part 2 Provides guidance on heat exchanger analysis, sizing, and specification.
2.7.2 Pumps Specifies pump type, supports, materials, and motor.		Section 4-4 Part 6 States that pumps required for both collector and storage loops; provides guidance on calculating flow path pressure drop, pump sizing, and pump specification.

Table 4-1 Cross references to the training manual TM5-804-2 and specification notes that can help clarify the specification requirements

Section 13600 Specification	Guide Specification	TM5-804 Training Manual
2.7.3 Pipe Insulation Specifies thermal performance: should be the same as insulation for 15 psig steam piping and should be able to withstand up to 400 degrees F within 1.5 feet of collector absorber surface and 250 degrees F at all other locations.		Section 4-4 Part 3(c) Recommends preformed, closed-cell polyisocyanurate insulation.
2.7.4 Expansion Tank Specifies expansion tank construction and testing. States that expansion tank must have an elastomeric bladder that separates the system fluid from the tank walls.	Note N Explains expansion tank sizing criteria; specifies the following information on drawings: volume (acceptance and total), materials (for both tank and bladder), and pressures (maximum relief, system cold fill, and precharge).	Section 4-4 Part 4(a, b, c, d) Provides guidance on expansion tank operation, determination of acceptance volume, and determination of design pressures.
2.7.5 Heat Transfer Fluid Requires collector loop fluid to be food-grade uninhibited propylene-glycol/water solution, solar collector loop fluid to be potable water.	Note O Allows water to be used as heat transfer fluid for direct circulation systems. Specifies the following information on drawings: use of 30 or 50 percent uninhibited food-grade propylene-glycol and distilled water solution, concentration level, and note of tamper-resistant seal requirement.	Section 3-3(b5) and Section 4-4 Part 1 Provides general guidance; explains criteria for determining whether 30 or 50 percent solution should be used.
2.8. Control Equipment Provides specifications for differential temperature control equipment, thermistor temperature sensors, sensor and control wiring, flowmeters, and sight flow indicators.	Note P States that requirements for differential temperature controllers may change as manufacturers begin producing controllers specifically for solar energy systems.	Section 4-5 Provides additional guidance on differential temperature controllers, temperature sensors and locations, and monitoring equipment.
3.1.1.1 Collector Installation Requires that collectors be removable for maintenance, repair, and replacement.	Note Q Specifies that collector tilt angle be site latitude within plus or minus 10 degrees. Specifies the following information on drawings: title angle, elevation of back of collectors off roof, and piping location and elevation.	

4.5 Recommendations

The specification is generally appropriate considering that the COE's specification is intended for medium-size solar water heating systems (1000 to 3000 ft^2). There are some requirements (refer to Appendix D) that can increase the cost of a system, but the specification is not requiring a "gold plated" system. In all likelihood, the installed cost of a system that is designed per this specification would probably be within the price range normally seen for systems of this size.

However, the specification should be somewhat flexible in the flat-plate collector design. The specification should stay with flat-plate collectors, but should be modeled after the performance specification for flat-plate collectors presented in Appendix E. This specification relies heavily on SRCC/FSEC rating and certification.

For any projects that could potentially use evacuated-tube collectors or trough collectors, the STDAC can assist in the evaluation of the feasibility of these projects. These systems should be evaluated on a case-by-case bases or for special demonstration projects. By considering these collectors, the COE will be adding flexibility in their overall solar energy program.

Finally, the COE may want to consider adding to the specification's reference section the ASHRAE *Active Solar Heating System Design Manual.*[3] This manual is a thorough reference that covers the design of various active solar water heating systems.

3. ASRAE and SEIA (American Society of Heating, Refrigeration, and Air Conditioning Engineers and Solar Energy Industries Association). 1988. *Active Solar Heating Systems Design Manual.* Document 90003.

This page left intentionally blank.

SECTION 5 Conclusions

5.1 Generic Solar Feasibility Study

After reviewing the COE's generic solar feasibility study,[1] the STDAC did not find the results of the study to be biased against solar heat systems. We did not find the results to be influenced by unfair analyses, and agree with the generic study's conclusion that solar space heating and solar cooling are usually not economically feasible at this time. However, we do not believe that this will always be the case with solar water heating.

The approach used in the generic study for evaluating discounted payback (high fuel costs and low construction costs) is an acceptable method for determining the feasibility of a solar system. However, the generic study did not evaluate discounted payback for varying fuel costs and varying system costs. The generic study instead evaluated discounted payback at various fuel costs for a fixed solar system cost. As was discussed in this report, a simple payback analysis based on varying fuel costs and varying solar system cost is another approach that can be used for evaluating the economic feasibility of a solar system.

If the payback analysis for a solar system (simple or discounted) is evaluated by varying the system costs and fuel costs, the required fuel and sys-

1. COE-Tulsa. 1990. *Active Solar Feasibility Study for the Continental United States.* November 1990. Prepared by the U.S. Army Engineer District, Tulsa, OK, for the U.S. Army Engineer Division, Southwestern.

tem costs necessary to meet a certain payback can be identified. It is important that the range of fuel and system costs used in this type of analysis be realistic.

Because the COE needs to have a method for quickly identifying potential solar projects, without spending a lot of funds, the STDAC recommends that the COE use a screening system for the initial evaluation. The screening process should look at conventional fuel costs, required year-round hot water loads, and determine simple payback for the system of interest. If the screening tool indicates that the project may be feasible, then an in-depth analysis should be performed.

If the COE needs to continue with a solar feasibility study similar to the generic study, then a sensitivity analysis that evaluates the payback for varying fuel costs and varying system costs should be used as the measure for analyzing the feasibility of a system. This will identify the cost range (system and fuel costs) where a solar system will meet the desired payback period. This cost range would then be evaluated to determine if the costs are reasonable to consider. Based on the results of this type of analysis, the COE can then make recommendations regarding the use of solar water heating systems. If required, we can help the COE revise their standard method for evaluating solar water heating systems.

5.2 SOLFEAS

We found SOLFEAS to be an adequate program for performing economic feasibility analysis of solar heat systems. We did not find the program difficult to use, and the results seem to be reasonable. SOLFEAS results are comparable to our solar feasibility analyses. The main difference between SOLFEAS and our method are the system cost and maintenance and repair cost.

5.2.1 System Cost

From our evaluation of the SOLFEAS program, it appears that the system costs generated by SOLFEAS are on the high side (and hence, the generic study's "low" construction costs are actually significantly above average). Yet, the system costs are not unreasonably high. We do not find SOLFEAS' system cost estimates to be outside the cost range that is normally considered for installed solar system costs. Because installed system costs depend on several parameters, it is better to use a cost estimate based on specific project requirements. However, for an initial feasibility analysis it may not be practical to go to the trouble of obtaining a cost estimate. Instead, the project can be evaluated for a range of system costs.

It is the estimated system costs that are in question. In most cases, fuel costs are easily quantifiable.

5.2.2 Maintenance and Repair Cost

Flat-plate system maintenance and repair cost is a variable that is not well documented. We do not have historical records on flat-plate system maintenance costs, and therefore have always based maintenance costs on rule-of-thumb estimates. Based on the maintenance cost estimates the STDAC used in the analyses, SOLFEAS predicted maintenance costs appear to be extremely high (4 to 18 times higher). However, for an initial solar feasibility study, maintenance and repair costs can be ignored. If an in-depth analysis is required, then maintenance costs should be included in the analysis.

5.3 Design Specification

The STDAC did not find the solar system design specification unreasonable. The specification requirements are not excessive and are appropriate for the type of solar systems that are considered by this specification. Also, we do not believe the design requirements will cause the system costs to be excessively high. The specification is fairly concise but it does not clearly define the type and size of solar water heating systems that it considers.

However, we feel that the specification's collector requirements could be relaxed to allow some flexibility in the design of the collector. This specification should stay with flat-plate collectors, but should develop a collector performance specification similar to the performance specification presented in Appendix E for flat-plate collectors. The STDAC and industry feel it is important that the collectors meet some minimum level of performance and that collector performance be certified. The collectors should have an SRCC rating or its performance must have been verified by an independent testing agency such as FSEC. We believe the flat-plate performance specification presented in Appendix E is sufficient and would prevent poor-quality collectors from being supplied.

5.4 Demonstration Program for Solar Heat Systems

The standard solar system that the COE requires for water heating is an appropriate design. This standard system requirement was set up to help minimize variations in system design and prevent the installation of poor-quality systems. However, this approach limits the use of other solar heat technology at Army installations. We believe the COE may be in a position to evaluate the use of other solar heat systems besides flat-plate systems. A program designed to advance the installation of market-ready solar heat systems could be used as a vehicle for showcasing appropriate solar heat technologies.

If the COE is interested and feels it is warranted to start a solar heat technology demonstration program, then Sandia would like to assist in the development of such a program. To help in evaluating the merits of such a program, the STDAC can provide the COE with an initial proposal for starting this program and give examples of projects that could be accomplished under a demonstration program. To help the U.S. government advance their energy conservation efforts, programs such as a solar heat program need to be investigated.

References

ASRAE and SEIA (American Society of Heating, Refrigeration, and Air Conditioning Engineers and Solar Energy Industries Association). 1988. *Active Solar Heating Systems Design Manual.* Document 90003.

Bennett, C.W. 1995. "Solar-heat Technology — A Primer." Accepted for Publication in the *ASHRAE Journal.* Scheduled print date: September 1995.

COE. 1990. *Section 13600 Solar Water Heating Equipment Specification.*

COE. 1990. *Guide Specification for Military Construction.* September 1990. CEGS-13600.

COE-Ft. Worth and CERL. 1993. *SOLFEAS: The U.S. Army solar feasibility study design tool, Version FY94.* December 1993. Prepared by BLAST Support Office and the U.S. Army Construction Engineering Research Laboratories, Champaign, Illinois.

COE-Tulsa. 1990. *Active Solar Feasibility Study for the Continental United States.* November 1990. Prepared by the U.S. Army Engineer District, Tulsa, OK, for the U.S. Army Engineer Division, Southwestern.

DOA (Department of the Army). 1992. *Technical Manual: Domestic and Service Water Active Solar Energy Preheat Systems.* February 1992. TM 5-804-2.

Marion, W. and D. Myers. 1992. *A Comparison of Data from SOLMET/ ERSATZ and the National Solar Radiation Data Base.* NREL/TP-463-5118, DE93000018. Printed November 1992. National Renewable Energy Laboratory: Golden, Colorado.

NREL. 1994. *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* NREL/TP-463-5607, DE93018229. Printed April 1994. National Renewable Energy Laboratory: Golden, Colorado.

NREL. 1992 and 1995. *National Solar Radiation Data Base (1961-1990).* Prepared by the National Renewable Energy Laboratory: Golden, Colorado. (Volume 1, *User's Manual,* printed September 1992, distributed by the National Climatic Data Center, Federal Building, Asheville, North Carolina 28801; Volume 2, *Final Technical Report,* printed January 1995).

President of the U.S. 1994. *Energy Efficiency and Water Conservation at Federal Facilities.* Executive Order 12902, March 8, 1994. 59 FR 11463, Vol. 59, No. 047.

Robert Snow Means Co. 1990. *1990 Means Mechanical Cost Data.* RS Means Co. Kinston, Massachusetts.

APPENDIX A

Microsoft Excel Spreadsheet for Simple Payback Analysis

Attached is a 3.5-inch diskette containing the file titled "PAYBACK.XLW." Microsoft Excel 5.0 for Windows is required to run this file.

To use this spreadsheet file, follow the instructions provided below:

1. Copy the PAYBACK.XLW file into your Excel data directory.
2. In Excel, open the PAYBACK.XLW file and press the "Find Site Location" button in Section 1 of the spreadsheet to choose, from a list of site locations, the location closest to your area. Scroll through the list using the spreadsheet scroll bars to find the site location you want. You cannot add a new location. After entering the location number, you will return to the main screen.
3. The "average" and "good" performance will be calculated for the chosen site location in Section 2 of the spreadsheet.
4. Enter your collector and fuel information in the white cells provided in Section 3 of the spreadsheet.
5. The data can be viewed on-screen by clicking the REPORTS tab at the bottom left side of the screen. Click the PAYBACK tab to return to the main screen.
6. Press any of the three print buttons in Section 4 of the spreadsheet ("Print Flat Plate Results," "Print Evacuated Tube Results," "Print All Results") for a hard copy of the results.

Questions regarding this spreadsheet can be forwarded to Phyllis Blair at (505) 845-3310.

This pa

APPENDIX B

Identifying Cost-Effective Applications

This page left intentionally blank.

A solar energy system recovers its initial investment by displacing auxiliary fuel with solar energy. The amount it displaces is equivalent to the amount of useful energy it delivers to the load divided by the efficiency of the auxiliary heating equipment. The annual amount of money a solar system saves (*annual energy savings*), S ($ per year), can therefore be expressed as

$$S = (E_l \, C_{af} / \eta_{ae}) - C_{op},$$

Where E_l is the energy delivered to the load by the solar system (Btu per year), C_{af} is the unit cost of the auxiliary fuel ($ per Btu), η_{ae} is the efficiency of the auxiliary heating equipment, and C_{op} represents the annual operating costs of the solar system ($ per year).

To screen for potentially cost-effective applications, *simple payback analysis* divides the annual energy savings, S, into the initial cost of the system to determine how many years are necessary to recover ("pay back") the initial investment. A solar system is cost-effective if the payback period is substantially less than 20 to 25 years, the commonly expected lifetime of solar systems. Government agencies usually require a 10 year payback period, while private companies may require 5 years or less.

To estimate a potential application's annual energy savings, first size the collector array. When sizing the array, it is very important to avoid excess capacity. Excess capacity can greatly lengthen the payback period by increasing initial cost without adding any appreciable energy savings. For example, solar space heating systems have longer payback periods than solar DHW heating systems because of their excess summertime capacity that idles throughout the summer. (Systems with excess capacity are also prone to overheating problems.) A useful rule-of-thumb to help avoid excess capacity is to size the array to deliver no more than 80% of the daily load each month. This rule-of-thumb usually results in arrays satisfying 60% to 80% of the application's annual load.

For each month, first divide 80% of that month's average daily load, L_{DAILY} (Btu or J per day), by the amount of daily radiation incident on one unit area of collector surface, I_{DAILY} (Btu per day per square foot or J per day per square meter). Next divide this amount by η_{DAILY}, where η_{DAILY} is the expected daily operating efficiency of the system (daily heat delivered to the load divided by the daily amount of incident radiation). Expressed algebraically,

$$\text{Array Size} = (0.80 \bullet L_{DAILY})/(I_{DAILY} \bullet \eta_{DAILY}).$$

Last, compare the array sizes for all the months and select the smallest.

Data used for I_{DAILY} are currently available from a number of sources including two recent publications by the National Renewable Energy Laboratory (NREL). The first, *Shining On — A Primer on Solar Radiation Data*, explains the nature of solar radiation data and how it is obtained, with discussions on how climate, geography, and atmospheric conditions cause solar radiation to vary. The second NREL publication, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, contains data for 250 sites. For each month of the year, the manual contains average daily values for incident direct-beam radiation for concentrating collectors, and global radiation values (the sum of direct-beam and diffuse radiation) for non-concentrating collectors facing south at various tilt angles. Both publications are available from NREL (1617 Cole Boulevard, Golden, CO 80401-3393, 303-275-4099).

Information on η_{DAILY} is not as readily available. Ratings and performance data on individual collectors are available, but η_{DAILY} generally is lower than the individual collector's rated efficiency for reasons such as piping thermal losses, storage/collector interaction, control strategies, and non-steady state operating conditions. Also, η_{DAILY} is not constant; it depends on the prevailing weather conditions and also on whether the collected energy is delivered directly to the load or stored for later use. However, for screening purposes, the collector's rated steady-state efficiency for η_{DAILY} may be used.

Figure 1, a typical collector rating curve, shows the steady-state efficiency for a liquid-based flat plate collector with one glass cover. The curve is of the form $\eta = mX + b$ where X is a parameter equal to the temperature difference between T_{fi}, the temperature of the fluid entering the collector, and T_{amb}, the temperature of the surrounding air, divided by the incoming solar radiation , I (Btu per square foot per hour):

$$X = (T_{fi} - T_{amb}) / I.$$

Values for m and b in Figure 1, from ASHRAE's *Active Solar Heating Systems Design Manual*, represent a typical "good" liquid-based flat-plate collector.

The parameter X varies over different ranges, depending on the application. For example, Figure 1 shows ranges taken from Chapter 34 of the ASHRAE 1992 *Systems and Equipment Handbook* for pool heating, domestic hot water (DHW) heating, space heating, and space cooling. One way to screen applications is to assume that η is the maximum efficiency in the application's range, η_{max}. In Figure 1, η_{max} is about 0.65 for DHW heating and just over 0.50 for space heating. Using η_{max} is a "best-case scenario" to quickly screen applications that are not cost-effective from those that warrant further analysis. The *Active Solar Heating Systems Design Manual* also contains *m* and *b* values for evacuated tube collectors and air flat-plate collectors.

Rather than using ASHRAE typical curves, actual collector ratings could be used instead. Ratings for non-concentrating collectors are available from the Solar Rating and Certification Corporation (SRCC, 777 North Capitol Street, Washington, D.C. 20002, 202-383-2570). The SRCC, an independent, non-profit organization, certifies and rates both the durability and performance of collectors using ASHRAE standards for glazed and unglazed collectors. All SRCC-certified collectors bear the SRCC label, which is proof that an independent agency has verified the performance and durability of the collector.

For different operating temperatures, the labels indicate how much energy (Btu or J per panel per day) the collector could deliver during clear days, mildly cloudy days, and cloudy days. Simply divide these rating values into 80% of the daily load to estimate the array size for a given application. These ratings also allow easy comparison of different collectors because they normalize their performance to the same conditions.

Performance ratings for concentrating collectors are available from their respective manufacturers. Also, the National Solar Thermal Test Facility at Sandia National Laboratories has issued performance reports on several concentrating collectors, but does not issue certifications of performance to manufacturers.

Example

To illustrate how to identify potentially cost-effective applications, Table 1 shows a solar DHW heating and economic analysis for a hypothetical 400-inmate prison near Phoenix, Arizona. The analysis considers a direct-circulation system, using liquid flat-plate collectors. Daily DHW consumption is 35 gallons (0.132 m^3) per day per inmate, or

14,000 gallons (53 m^3) per day. The DHW supply temperature is 120°F (50°C). The average city water temperatures, T_{CW}, are from ASHRAE's *Active Solar Heating Systems Design Manual.* The average daily thermal loads for each month, L_{DAILY}, can be expressed as follows:

$$L_{DAILY} = 14{,}000 \text{ gallons/day} \bullet 8.3 \text{ Btu/(gallon°F)} \bullet (120°\text{F} - T_{CW})$$

or

$$L_{DAILY} = 53 \text{ m}^3\text{/day} \bullet 4.2 \text{ MJ/(m}^3\text{°C)} \bullet (49°\text{C} - T_{CW})$$

Data on average daily radiation, I_{DAILY}, is taken from the *NREL Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors* for flat-plate collectors with a tilt angle equal to Phoenix's latitude. Assuming η is 0.65 (from Figure 1), Column 5 shows monthly array sizes that could deliver 80% of each month's average daily thermal load. The smallest of these sizes, 2,640 ft^2 (245 m^2), delivers 80% of September's load. Larger arrays would be less cost-effective because they would likely idle in September.

The table considers two scenarios: using natural gas for heating at $3.00 per million Btu ($2.85 per billion J) and using electricity for heating at $0.10 per kWh (demand charges are ignored). The monthly savings for each scenario (Columns 7 and 8) are the average daily savings times the number of days in the month. (The average daily savings assume auxiliary heating equipment efficiencies of 70% for natural gas and 100% for electricity and do not reflect the operating costs of the solar DHW system.) The annual energy savings are $5,535 for natural gas and $37,829 for electricity. Assuming the array costs $35 per square foot, the payback period for natural gas is

$$(\$35/ft^2 \bullet 2{,}640\ ft^2) / \$5{,}535 = 17 \text{ years},$$

and the payback period for electricity is

$$(\$35/ft^2 \bullet 2{,}640\ ft^2) / \$37{,}829 = 2.4 \text{ years}.$$

Since most applications require a 10-year simple payback, the natural gas scenario is not cost-effective. However, the electricity scenario warrants further analysis.

Figure 1. Typical collector efficiency curve for "good" liquid flat-plate collectors. Values for m and b taken from the ASHRAE *Active Solar Heating Systems Manual.* Note that ranges for the parameter X, T_{fi} - T_{amb} / I, for different applications are provided in the figure.

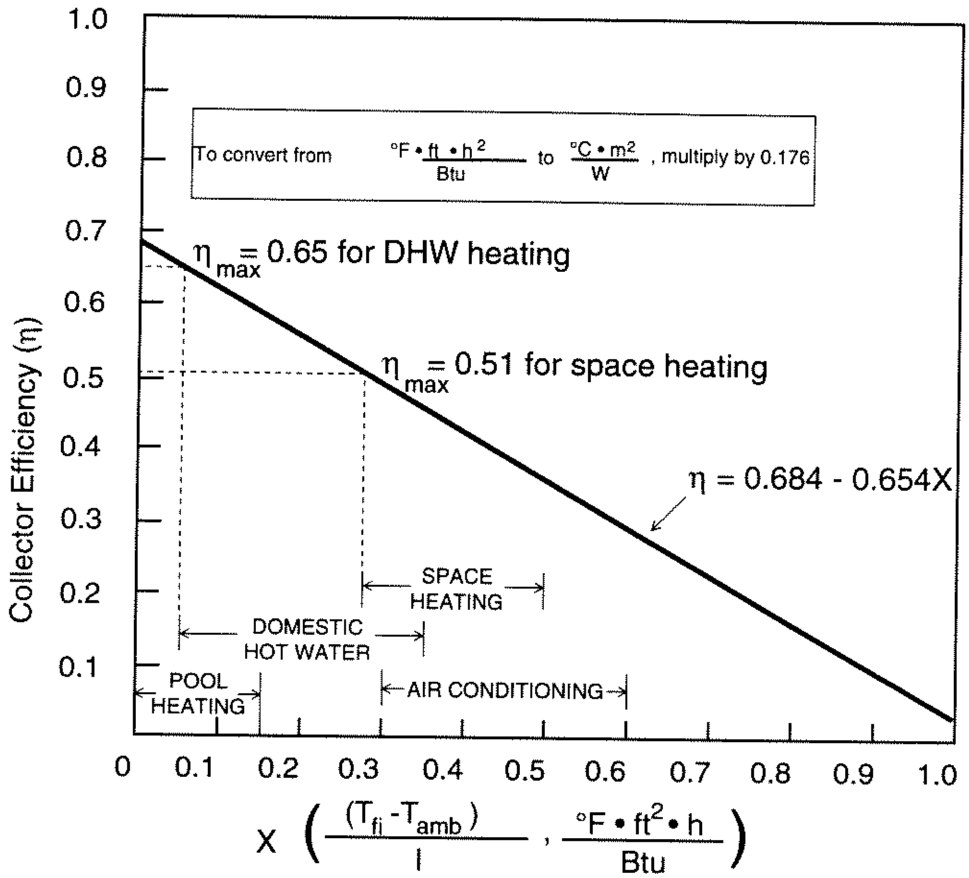

Table 1. Solar DHW analysis for a hypothetical 400-inmate prison near Phoenix, Arizona.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Month	T_{CW} (°F)	L_{DAILY} T(Btu/day)	I_{DAILY} (Btu/day/ft^2)	**Array size for 80% of** L_{DAILY} (ft^2)	**Solar energy delivered by a 2,640 ft^2 array at 65% efficiency (Btu/day)**	**Monthly Savings @ $3.00 per MMBtu ($2.85 per GJ)**	**Monthly Savings @ $0.10 per kWh**
Jan.	48	8,366,400	1,618	6,360	2,776,488	$369	$2,521
Feb.	48	8,366,400	1,903	5,410	3,265,548	$392	$2,678
March	50	8,134,000	2,125	4,710	3,646,500	$484	$3,311
Apr.	52	7,901,600	2,347	4,140	4,027,452	$518	$3,539
May	57	7,320,600	2,379	3,790	4,082,364	$542	$3,707
Jun.	59	7,088,200	2,316	3,770	3,974,256	$511	$3,492
Jul.	63	6,623,400	2,189	3,720	3,756,324	$499	$3,411
Aug.	75	5,229,000	2,252	2,860	3,864,432	$513	$3,509
Sept.	79	4,764,200	2,220	2,640	3,809,520	$490	$3,348
Oct.	69	5,926,200	2,062	3,540	3,538,392	$470	$3,213
Nov.	59	7,088,200	1,776	4,910	3,047,616	$392	$2,678
Dec.	54	7,669,200	1,554	6,070	2,666,664	$354	$2,421
Annual						$5,535	$37,829

To convert from °F to °C, subtract 32 and divide by 1.8.

To convert from Btu/day to J/day, multiply by 1054.

To convert from ft^2 to m^2, multiply by 0.093.

APPENDIX C

Comparison Study of SOLFEAS versus STDAC's Solar Evaluation Method

This page left intentionally blank.

Background

This report summarizes the comparison study regarding SOLFEAS and the method currently used at SNL to evaluate solar system performance and economics. Two projects which were recently evaluated by SNL personnel were used in this study. The first project is a solar domestic hot water system for a Visitors Quarters building at Fort Huachuca in southern Arizona. This system was designed by the Corps of Engineers but was never installed and consists of a closed-loop glycol system and 320 square feet of flat-plate collector mounted on the roof of the building. SNL recently reviewed the design, estimated the energy production and natural gas savings and the Savings to Investment Ratio for this project.

The second project is a study that SNL performed for Peterson Air Force Base. This project consists of using flat-plate solar collector to supply pre-heated water to the barracks cafeteria. The envisioned system consists of a closed-loop glycol system and 1,800 square feet of flat-plate collectors, ground mounted, in Colorado Springs, Colorado.

The SNL analysis for these two projects was accomplished by using the following procedure:

1. Determine the load and the site requirements. This is done by installing a non-intrusive flow meter on the cold water make-up to the hot water system in the appropriate building. The meter is left installed for a 24 hour period. The hot water load is then calculated using the total flow for the 24 hour period, the inlet water temperature and the hot water set point temperature.
2. Size the array using the peak solar day. To ensure that the array will not be oversized, the hot water load is divided by the solar energy available during the peak solar day divided by the expected solar system efficiency.
3. Determine monthly radiation available using INSOL. INSOL can produce monthly summaries of solar radiation available for various solar technologies and array

orientation using Typical Meteorological Year data. For these projects, flat-plate collectors, facing due south and latitude tilt was chosen.

4. Develop a spreadsheet and calculate solar energy delivered and conventional fuel savings. The INSOL data is imported into a spreadsheet. For each month the radiation available is multiplied by the size of the array and the expected solar system efficiency, this results in the thermal energy delivered to the hot water that is produced by the solar field. The natural gas displaced is calculated by dividing the solar energy delivered by the estimated conventional boiler efficiency.
5. Use historical costs and/or work with the solar industry to develop a conceptual cost estimate for an installed system. Maintenance cost are then estimated considering the solar technology applied, the location of the array and historical data available for similar systems.
6. The economic analysis is then performed based on the customers requirements (LCCID computer program for the military).

Example 1, Ft. Huachuca

In 1993, the Solar Thermal Design Assistance Center (STDAC) was asked to survey Ft. Huachuca and analyze the most promising solar thermal applications. The Visitors Quarters buildings were selected as they have a reasonably constant seven day a week, 365 day a year hot water load. Base personnel presented the STDAC engineer with a previously developed detailed design for a solar hot water pre-heat system for one of the Visitors Quarters Buildings. The load of the building was measured and the cost estimated for the solar system was based on the detailed design.

The 320 square foot solar system was used as the basis for the comparison between the SNL method and the SOLFEAS program. A summary of the results for this project are shown in the following table.

	Array ft^2	Solar Fraction	Solar Energy MMBTU/ft^2	Nat. Gas Displaced MMBTU/ year	Blr. Effic.	1st Cost $/ft^2	Maint. Cost $/yr
SNL	320	0.6	0.347	159	0.70	61.50	32
SOLFEAS	295	0.6	0.379	147	0.75	110.30	592

Conclusions

- Reasonable agreement with array sizing and energy production (within 10%).
- SOLFEAS predicts a very high 1st cost.
- SOLFEAS predicts a very high annual maintenance cost. It has a rather significant impact in the economic analysis because it is an annual sum. Typical reported cost are in the range of 10 to 20 cents per square foot per year, sometimes as high as 50 cents. As this is a roof mounted system to be located in a mild climate area, $0.10/ft^2 was chosen for this project.

Example 2, Peterson Air Force Base

In 1993, the Solar Thermal Design Assistance Center (STDAC) was asked to survey Peterson Air Force Base and analyze the most promising solar thermal applications. The cafeteria for the barracks buildings was selected as it had a seven day per week hot water load and ample area for a ground mounted system.

The 1,800 square foot solar system was used as the basis for the comparison between the SNL method and the SOLFEAS program. A summary of the results for this project are shown in the following table.

	ft^2	Energy $MMBTU/ft^2$	Nat. Gas Displaced MMBTU/yr	Blr Effic.	1st cost $\$/ ft^2$	Maint. Cost $/year
SNL	1,800	0.323	893	0.65	44.44	500
SOLFEAS	1,654	0.290	639	0.75	81.74	2,028

Conclusions

- Reasonable agreement with array sizing and energy production (within 10%).
- SOLFEAS predicts a high 1st cost. (SNL cost was from rough estimate given by a solar installer local to Peterson AFB)
- SOLFEAS predicts a very high annual maintenance cost. It has a rather significant impact in the economic analysis because it is an annual sum. Typical reported cost are usually in the range of 10 to 20 cents per square foot per year and $0.28 per square foot was chosen as this would be a ground mounted system located near a base road and is located in a harsh winter time environment.

Simple Payback and Savings to Investment Ratio (SIR)

The last step in this comparison analysis was to take all the numbers generated by SOLFEAS and enter those values into LCCID to get a direct comparison of economic analysis. For the Peterson project, SOLFEAS generated "0"s for the simple payback and the Savings to Investment Ratio (SIR). In addition, SOLFEAS did not calculate a simple payback for the Ft. Huachuca project.

Using the 60% solar fraction scenario at Ft. Huachuca, SOLFEAS generated a SIR of 0.137 while LCCID calculated 0.30 using the same construction, maintenance, and displaced natural gas values.

Conclusions

SOLFEAS array sizing and energy production predictions are reasonable for the two areas selected in this study.

SOLFEAS first cost estimations are nearly twice those developed by SNL. The first cost projection for the Peterson AFB project was developed by a solar installer who visited the site and, therefore, should be a reasonably accurate estimate. In addition, it exactly matches an installed cost for a similar system in Virginia.

SOLFEAS predicts an extremely high maintenance cost. Maintenance cost for most flat plate systems are not well documented; however, they are well documented for several parabolic trough systems at about $0.25/ft^2/yr. It is reasonable to assume that flat plate systems would require less maintenance as there are fewer moving parts.

There is little to compare regarding the economic analysis for these two projects; however, the Savings to Investment Ratio for the Ft. Huachuca project were not in close agreement. Military programs were used in both analysis methods.

SOLFEAS is limited to analyzing flat-plate collector systems. For many applications flat-plate collectors are not the best choice, from both a performance and from an economic view.

This page left intentionally blank.

APPENDIX D

Summary of Industry's Review of the Section 13600 Solar Water Heating Equipment Specification

This page left intentionally blank.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
General Comments	1	**First Review:** The specification appears to be written totally around large scale generic closed loop systems. However, there are a number of reasons why other generic types should be considered. For example, simple 1 to 3 panel systems should be considered. **Second Review:** Reviewers not clear why COE considers only liquid flat-plate closed loop systems. Need to clarify in general section systems that are covered by this spec. Collector sub-system should be SRCC, and or FSEC rated.	**First Review:** We agree. Also, the specification only allows liquid flat-plate collectors. The COE should not discriminate against other types of SRCC rated collectors or concentrating collectors with proven history. **Second Review:** Not clear about systems covered under this specification. TM5-804-2 sections 3-2 & E-9 state Army's goal for standardize solar system. Need to address standard system in general section, give size range and general system requirements (closed loop, flat-plate, etc.). However, how does Corp evaluate small or large systems that would not be covered by this spec? Examples: small drain-back systems (500 ft^2 or less) or an energy service contract where a trough systems could be used?
	2	**First Review:** In regards to the section dealing with air vents, balancing valves, isolation valves: Less is more. Unless there is a rock-solid reason for a valve or component, leave it out.	**First Review:** We agree. See the following comments: Paragraph 2.2.10 Calibrating Balancing Valves, Comment No. 1. Paragraph 2.2.1.1 Air Vents, Comment No. 2 Paragraph 3.1.3.4 Piping, Valves, and Accessories, Comment No. 1. **Second Review:** Since spec is for 1000-3000 ft^2 flat-plate systems many of the hardware requirements are applicable. However, if a solar contractor or manufacturer has suitable alternatives that are proven to be acceptable and less expensive, then there should be flexibility built into the spec to allow for such alternatives. Overall we agree that the specs' hardware requirements are not unreasonable.
1.1 References	1	**First Review:** The solar glass energy transmittance testing procedure is actually ASTM E-424, not ASTM C-1048.	
	2	**First Review:** We recommend adding SRCC and FSEC as certifying agencies for collector ASHRAE test.	**First Review:** The COE should require non-concentrating collectors to be SRCC rated. If the COE is interested in technologies that the SRCC does not rate (such as concentrating collectors), the COE needs to protect themselves contractually, probably on a case-by-case basis. **Second Review:** STDAC strongly feels SRCC rating or FSEC testing should be required.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
1.1 References (continued)	3	**First Review:** The Uniform Solar Energy Code may be able to replace all the listed specifications and codes.	**First Review:** We disagree. **Second Review:** After reviewing this code and comparing it to the plumbing code, the Uniform Solar Energy Code sufficiently covers solar systems that are applicable to this specification. This code does refer to the other codes. We agree with the industry's comment.
1.2 System Description	1	**First Review:** Recommend revising to read "...collector array, **its mounting system**, ..." Reason: A strong emphasis should be placed on the structural integrity of racks and mountings, as well as water-proofing details.	**First Review:** We agree. See the following comments: Paragraph 1.3 Submittals SD-04 Drawings, Comment No. 2. Paragraph 2.5.3 Supports, Comment No. 1 Paragraph 3.1.1.1 Collector Array, Comment No. 2. Paragraph 3.1.1.3 Array Support, Comment No. 1.
	2	**First Review:** Recommend adding to line 6: "...closed loop, or potable water heat transfer fluid in an open loop, heat..." Reason: This change allows for closed loop as well as open loop. **Second Review:** Not too likely; hard time proving cost effectiveness of year round hot water; training manual only for hot water	**First Review:** We recommend that the COE revise the specification to allow applications other than service water heating and systems other than those described in this paragraph. **Second Review:** STDAC did not realize COE's standard solar system requirement. We agree that the Corps needs to stay with a standard system requirement. See STDAC's comment in general section comment #2.
	3	**First Review:** Recommend adding to line 7: "...exchanger, expansion tank, and accessories **that may be** required for the operation of the system..." Reason: This change is allows thermosyphoning systems which do not require pumps, controls, or instrumentation.	**First Review:** See above comment.
1.3 Submittals SD-01 Data\Spare Parts	1	**First Review:** "ensure efficient operation for a period of **at least** 120 days.." This sub-section is confusing since the title is "Spare Parts" but reads as if all components of the system must be listed along with current price and source of supply. The last line: "and a list of additional items recommended by the manufacturer to ensure efficient operation for a period of 120 days." appears as though systems fail after 120 days. Properly installed systems using quality components should operate efficiently for a much longer period (years).	**First Review:** We recommend that COE include as a bid document a list of all equipment for which they require submittals, and a description of the type of submittal required. We also recommend that the COE omit the spare parts requirement. **Second Review:** Should require spare part requirements for the equipment that are not readily available. Should not require spare collectors, pumps, etc.
1.3 Submittals SD-04 Drawings	1	**First Review:** ..shall show proposed layout (delete "and") , anchorage and, as required, waterproofing details for roof and wall penetrations, for the equipment and appurtenances. **Second Review:** Contractor responsible for as-built drawings.	**First Review:** We agree with comment, but see comment below.

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
1.3 Submittals SD-04 Drawings (continued)	2	**First Review:** Would not the system design engineer be responsible for submitting drawings? If the Corps was to subcontract with the equipment supplier, then yes, the supplier would be responsible.	**First Review:** We agree with comment. Much of what this paragraph requires is normally prepared by the system designer (Architect/Engineer).. We recommend that the COE only require as-built drawings from the contractor.
1.3 Submittals SD-06 Instructions	1	**First Review:** It would seem that a minimum size system should be specified before "methods of balancing and testing flow" in the system can be justified. As specified elsewhere. reverse return plumbing with roughly equal lengths feeder and return lines, plus calculated and specified (or design built) pipe sizes and pumps, will assure equal flow in smaller to medium size systems. Leave in methods of testing. **Second Review:** Leave in methods of testing.	**First Review:** We recommend the COE omit the reference to methods of balancing and testing flow in this paragraph. **Second Review:** STDAC misunderstood spec is only for medium flat plat (1000-3000 ft^2); should leave methods of testing. Balancing valves needed.
	2	**First Review:** Simple means, such as a pressure gauge and some thermometers, are easy ways to check proper operation in most, except very large systems.	**First Review:** We agree, but do not feel that the specification, as written, discriminates against these methods.
1.3 Submittals SD-08 Welding	1	**First Review:** This sub-section is not required since welding is not a normal part of the solar energy system or its installation.	**First Review:** We disagree with comment. Welding is sometimes necessary on solar projects.
1.3 Submittals SD-09 Inspection and Testing	1	**First Review:** Under "Inspection and Testing" heading, it is not clear to me what an independent agency is testing and certifying for.	**First Review:** We recommend that the COE omit the "independent testing agency" requirement and require the installation contractor to test the operation of the system and set flows. **Second Review:** Clarification of "independent testing agency" needed. System field inspection and testing important, need to spell out what COE wants.
	2	**First Review:** Does this refer to FSEC or SRCC? If yes, no problem. If no, this will add significant cost to projects.	**First Review:** See above comment.
	3	**First Review:** This is unclear. Do these specs require a testing agency or lab to inspect and certify each actual installation, or does this refer to the equipment used in the installation?	**First Review:** See above comment.
1.3 Submittals SD-19 Operating and Maintenance Manuals	1	**First Review:** Specify who is responsible for the "Field Training Course."	**First Review:** As with all sections of this specification, this contractor is responsible for the "Field Training Course."

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
	2	**First Review:** The line which states, "Manuals shall be approved prior to the field training course," infers that a field training course is required. Field training should not be part of the specifications for a solar water heating system but should be a separate activity under a separate contract. The operating manuals with step by step procedures should be sufficient. We recommend deletion of the portion of the line prior to the "field training course".	**First Review:** Disagree with comment. The installing contractor should provide the owner's maintenance personnel with training on system operations and maintenance.
1.5 Qualifications	1	**First Review:** Delete "...Procedures and welders shall be qualified...to be accomplished." Replace with "Solar installers shall be qualified in accordance with the appropriate license or certification for solar installations." This will specify that solar installers be appropriately licensed and have experience relating to the solar industry.	**First Review:** This paragraph specifically addresses welding requirements, not solar system installation. We recommend that the COE revise the paragraph to explicitly state the applicable code "under which the welding is specified to be accomplished."
2.1.1 Standard Products	1	**First Review:** Delete "...Equipment shall be supported by a service organization that is, in the opinion of the contracting officer, reasonably convenient to the site." This section is the responsibility of the installer.	**First Review:** Agree.
	2	**First Review:** Suggest dropping "...Equipment shall be supported by a service organization that is, in the opinion of the contracting officer, reasonably convenient to the site." Too subjective a clause. Also, experience has shown that inferior local companies have been unjustifiably favored over better quality from further away. Also, is this clause discriminatory? Is it found in standard non-solar specs?	**First Review:** See comment above.
2.15 Equipment Guards and Access	1	**First Review:** Suggest specifically excluding pumps - not to be insulated.	**First Review:** Agree. **Second Review:** But spec probably doesn't mean this.
2.1.6 Special Tools	1	**First Review:** What does this refer to specifically?	**First Review:** We recommend COE omit this requirement. **Second Review:** Seems to be boiler plate information.
2.2.1 Copper Tubing	1	**First Review:** Why specify Type L tubing and L or M collector risers? Why not type M or better?	**First Review:** We agree with comment.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
2.2.1 Copper Tubing (continued)	2	**First Review:** ...type K where buried, type M above ground, **except in the case of soft copper tubing, which must be type L.** Collector risers...Reason: Using Type M copper for array piping rather than the more expensive Type L can make a significant cost reduction. Type M is allowed by the UPC, 6" above grade in residential and commercial applications. Some municipalities do not allow underground copper piping because of failures due to soil chemistry attack.	**First Review:** See comment above.
	3	**First Review:** Suggest strongly dropping description of collector risers in this section, which on piping, and should not treat collectors like piping.	**First Review:** We agree with comment.
2.2.2 Solder	1	**First Review:** Add **...or Sn96**. Reason: Lead-free solders are required in fitting up potable water systems.	**First Review:** Sn96 is already included in the specification. **Second Review:** Specification is adequate.
2.2.9 Relief valves, Pressure and Temperature	1	**First Review:** Why redundant valves on collector manifold and at expansion tank location? One relief would be adequate. This section would not be appropriate for use in "closed loop drain back" or "open loop" systems.	**First Review:** We recommend that the COE revise the specification to require pressure relief valves: • On the outlet of any collector bank that can be isolated with fluid inside the bank. Its discharge pressures should be below the collector maximum allowable pressure. • On storage tanks operating greater than 15 psig. The set pressure should be about 125% of the operating pressure but below the tank design pressure. Also, temperature relief valves are required on pressurized storage tanks.
	2	**First Review:** Again, system type should be considered. If this is an open system, OK. If closed loop, then perhaps a 35-75 psig valve should be considered. **Second Review:** Experience shows that the collector loop rating in closed-loop designs must be 150 psi to prevent boil out under stagnation. Could add to spec:"its discharge pressure should be below the collector maximum allowable pressure, but above normal stagnation pressure."	**First Review:** **Second Review:** Agree with comment, but 150 psi seems excessive. However, we do not have knowledge of this high of pressure requirements. Currently, the specification follows normal practice.
2.2.10 Calibrated Balancing Valves	1	**First Review:** Balancing valves are not necessary in most systems. Even large systems which are installed with reverse return flow are balanced and do not require balancing valves	**First Review:** We do not interpret this specification to require balancing valves. **Second Review:** STDAC misinterpreted spec. Section 3.1.3.6 calls for balancing valves. For this size of closed loop system, balancing valves are appropriate.

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
2.2.10 Calibrated Balancing Valves (continued)	2	**First Review:** See Comment for 1.3, SD-06	**First Review:** We recommend that the COE require manual air vents on array piping on indirect systems (closed-loop glycol). We also recommend that they require automatic air vents on direct systems. **Second Review:** Spec for closed-loop systems, require manual air vents. Spec requirement is sufficient.
2.2.11 Air Vents	1	**First Review:** ...air vents shall **be manually operated and** be provided with threaded...Reason: Automatic air vents are notorious for leaking, especially during/after stagnation conditions. In closed loop systems, this produces collection fluid and pressure losses.	**First Review:** We agree. **Second Review:** Manual air vents may not allow for complete purging of air, but they do not leak. Auto air vents help maximize system efficiency by purging all the air, but they can leak. TM5-804-2 recommends manual vents. ASHRAE design document recommends automatic air vents.
2.2.16 Pipe Supports	1	**First Review:** Stainless steel insulation shields are not necessary.	**First Review:** We agree. **Second Review:** Other alternatives such as galvanized or aluminum could be used.
	2	**First Review:** What is requested here?	**First Review:** We believe this paragraph addresses the protective shields used to protect the pipe insulation at pipe anchors, guides, and supports. We recommend that the COE clarify the paragraph.
2.4 Collector Sub-system	1	**First Review:** The entire section appears to have been written by a manufacturer with his collector in mind. **Second Review:** Important to add collector's minimum performance certified (FSEC, SRCC). Prefer all copper absorber to prevent corrosion as seen in bimetallic absorbers. Extremely important section and needs more consideration and subsequent review.	**First Review:** Liquid flat-plate collector, at a minimum should be constructed using low-iron tempered glass, an extruded aluminum frame, EPDM gasket, copper flow channels, and insulation that will not breakdown or out gas at the stagnation temperatures. **Second Review:** As written, the spec will eliminate good collectors that use aluminum absorber plates. Should require FSEC or SRCC rating. Agree with industry.
2.4.1 Solar Collector Construction	1	**First Review:** ..and shall be a minimum of 23 square feet....Comment: Many manufacturers sell 4x10,4x8, and 3x8 size collectors. Allowing the smaller size may result in room available for another collector, especially near the end of an array.	**First Review:** See comment above.

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
2.4.1 Solar Collector Construction (continued)	2	**First Review:** The specs' continued reference to net aperture are a mystery. ("net aperture area shall be as shown"). Obviously, gross areas are more relevant to show on plans -- to make sure specifier has actually allowed enough area -- not always the case. Also, all U.S. test results are given based on gross area.	**First Review:** See comment above.
2.4.2 Absorber plate and flow tubes	1	**First Review:** It is difficult to justify copper selective surfaces under many circumstances. **Second Review:** Black chrome a quality standard for collectors used for water heating: produces 15-20% more and doesn't cost that much more.	**First Review:** See comment above. **Second Review:** Discussions with Larry Lister indicated that CERL had bad experience with painted absorbers and prefer black chrome selective surfaces. Agree that black chrome selective coatings are a good standard to follow; however, there have been advances in selective surface paints, but the long term durability is still a question. Specification requirement is jsutified, and we agree with current requirement.
	2	**First Review:** There is no disputing that the black chrome-coated absorber surface delivers more energy. But it may well be worth considering cheaper, painted absorbers on retrofit/refurbish projects in lieu of the more expensive selective surface ($50 to $70 per absorber).	**First Review:** See comment above.
	3	**First Review:** Black chrome is specified. Many applications may not require black chrome and in fact not at all apparent for water heating. Currently there are a number of selective and moderately surfaces available in the market today.	**First Review:** See comment above.
	4	**First Review:** Why must the absorber be copper/black chrome? There can be better and more cost-effective alternatives. MAXORB is widely used in Europe. Black chrome has many environmental problems. Plastic swimming pool collectors would be highly effective for preheat applications in Hawaii. _____ makes a collector where the absorber plate is in direct contact with foam insulation. **Second Review:** One reviewer disagreed with the above comment: " the cost of storage and the high fixed cost of collector installation & piping does not justify a low output collector."	**First Review:** **Second Review:** Some of these comments do not pertain to the spec. We believe the spec requirement should be maintained to prevent unneeded maintenance problems.

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
2.4.2 Absorber plate and flow tubes (continued)	5	**First Review:** Suggest dropping "flow tubes shall be Type L or M. 1) Manufactured products such as collectors use industrial pipes not conforming to this description (if any requirement, the wall thickness might be given). 2) Collectors are heat exchangers: government specs do not generally prescribe material thickness in other types of heat exchangers. 3) This spec does not guarantee the quality it is looking for. It may be more productive to have the specifier pick a good product to write his spec around.	**First Review:** See comment above.
2.4.3 Cover Glazing	1	**First Review:** Suggest dropping clear and float and specifying a minimum solar energy transmittance. Reason: Float is not solar glass (depending on type, it has a very low transmittance) Solar glass is not correctly clear, it has an anti-glare etching. Suggest re-phrasing "Each collector shall have 1 single layer of cover glazing made of low-iron or water-white tempered solar glass with a minimum solar energy transmittance of 90.4%. The glazing shall be supported on the frame on all 4 sides."	**First Review:** See comment above.
2.4.4 Collector Insulation	1	**First Review:** Urethane foam should probably not be included.	**First Review:** See comment above. **Second Review:** Stagnation temperatures are probably too high for urethane insolation. We agree with comment.
2.4.6 Mounting and Assembly Hardware	1	**First Review:** SS fasteners may be needed in coastal climates, but not in dry desert climates.	**First Review:** Are these a big cost item? **Second Review:** Justified to keep requirement in the spec.
2.4.7 Warranty	1	**First Review:** Freight is generally not included.	**First Review:** We agree with comment.
	2	**First Review:** Suggest that the warranty required be no longer than for equivalent non-solar equipment. **Second Review:** Solar industry keeps being pushed into overly long warranties, supposedly to live down its bad old reputation. Solar warranties should be in-line with other heating products.	**First Review:** We agree with comment.
	3	**First Review:** Even though a 10-year warranty may be legitimate, what conventional heating equipment does the COE purchase with 10 year warranties?	**First Review:** See comment above.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
2.4.7 Warranty (continued)	4	**First Review:** The collector warranty against "failure of manifold or riser tubing" must exclude manufacturer's liability for freeze damage.	**First Review:** We recommend the COE revise this paragraph so that its requirements are more in line with warranties typically offered by solar manufacturers today. **Second Review:** Important not to have excessive warranties that penalizes solar. Agree that warranties should be in-line with other water heating products.
2.4.8 Solar Collector Performance	1	**First Review:** Much of this section is superfluous.	**First Review:** We agree and recommend the COE omit this section.
	2	**First Review:** Clarify that the minimum performance is on gross area (as all U.S. tests are given) and that it is based on the standard test flowrate (14.7 lb./hr/sf).	**First Review:** See above comment.
2.5.1 Net Absorber Area and Array Layout	1	**First Review:** There are many instances where there could be less than 4 collectors. The maximum number per bank is dependent on the nominal size of the collector i.e., if 40sf panels are used, then 7 would be a max. If 28sf collectors are used, may by manufacturers recommendation more per bank could be utilized.	**First Review:** We recommend the COE omit this section.
	2	**First Review:** Why only 7 collectors in a bank if more can still provide good flow distribution?	**First Review:** See above comment.
	3	**First Review:** See prior comments on this subject. Referring to "aperture area."	**First Review:** See above comment.
2.5.2 Piping	1	**First Review:** The requirement for array piping to be pitched 0.25" per foot is unreasonable. Waste pipe has this requirement due to solids. A requirement of 0.25" per 4 feet will allow adequate draining of the collectors. "Calibrated balancing valves shall be supplied at the outlet of each collector bank" is not required if the array is plumbed in reverse return configuration as specified. **Second Review:** Balancing valves good idea for system with multiple banks, silly on small systems. Specify size for requiring balancing valves.	**First Review:** We recommend the COE require 1/8" per foot. **Second Review:** Current spec does not consider drainback (spec for large systems). Use of balancing valve on large systems is needed. COE should specify what the minimum system size required for incorporating balancing valves. Spec is adequate for balancing valve requirements.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
2.5.3 Supports	1	**First Review:** I was unable to locate section 5500. TM-804-2 (8) (b) in this section appears adequate. It should be noted, however, that a number of manufacturers do test to wind loading code requirement. It would seem that these independent tests should be utilized and should become a component of Section (8) (b).	**First Review:** We agree with the specification, as written, except that its requirement that support structures be aluminum. **Second Review:** Discussions with Larry Lister indicated that the requirement of aluminum supports is due to the low maintenance with aluminum. However, STDAC feels that the requirement for all aluminum supports could significantly increase the collector system cost.
2.6.1 Storage Tank	1	**First Review:** Insulation should not be greater than that required for regular water heater. Normally, this is R-17. R-30 penalizes the solar energy system by requiring greater insulation than the traditional water heater. "Tank penetrations shall be designed to allow for connections to copper piping without risk of corrosion due to dissimilar metals, and shall be factory installed as indicated." This section should allow for the installer to use dielectric unions. See Section TM 5-804-2 and Section 4-3a (at the end).	**First Review:** Agree with industry.
	2	**First Review:** Commercially available solar storage tanks are insulated to a nominal R-14. To field insulate the recommended R-30 will result in significant added cost. **Second Review:** R-30 requirement penalizing solar, but tank temperatures in solar systems are higher (160-180°F) compared to standard hot water systems (130-140°F).	**First Review:** See comment above. **Second Review:** R-30 tank insulation is excessive. COE may want to reconsider requirement.
	3	**First Review:** The designer and economic considerations should dictate the volume of thermal storage and tank insulation. R-30 is excessive. Solar has to compete with conventional fuels and we know of no water heaters with such an amount of insulation.	**First Review:** See comment above.
2.7 Transport Sub-System	1	**First Review:** As in the case of residential or small systems, suggest that specifiers seek out factory assembled mechanical systems - heat transfer appliances - available from some manufacturers of collectors even for very large systems.	**First Review:** "Heat transfer appliances" are viable technologies. However, designers can adequately show their installation details on drawings and specify their performance on equipment lists. This specification focuses on larger systems that require much installation effort.
2.7.1 Heat Exchanger	1	**First Review:** The Uniform Solar Energy Code specifies that all heat exchangers used in solar water heating systems shall be of double wall vented construction if one transport fluid is potable water and the other fluid is anything other than potable water regardless of its toxicity.	**First Review:** Agree. **Second Review:** Section 4.4 of training manual TM5-804-2 should be noted for heat exchanger requirements. This section details heat exchanger fluid requirements, heat exchanger analysis , sizing and specifications.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
2.7.1 Heat Exchanger (continued)	2	**First Review:** Suggest re-phrasing in terms of an LMTD of 20°F.	**First Review:** Recommend showing the performance requirements on the drawings, not on the specifications.
2.7.2 Pumps	1	**First Review:** PV driven circulators should be considered/ They have been proven to be very reliable and efficient. Unable to locate reference 15250.	**First Review:** This specification does not discriminate against PV powered pumps.
	2	**First Review:** Why must the pumps be single stage? Why on a concrete foundation? (Sometimes they can be on a second floor steel gantry). Why must they have mechanical seals? (SNLA recommends packing glands for oil service.) Why do they need SS impellers and bronze casing if in a closed, corrosion free system? Sometimes space restrictions prevent the desired straight runs specified.	**First Review:** We recommend the following: • All-bronze pumps for direct circulation systems • All-iron pumps for indirect systems with inhibited glycol-based heat transfer fluids • Bronze-fitted pumps for drainback systems Packing is acceptable unless indicated otherwise on the drawings.
	3	**First Review:** ..on a concrete foundation, or other structurally sound detail. At no time should a pump be supported by the piping in which it is installed. The pumps shall...Reason: Although it is true that many (most?) fractional horsepower circulators are installed in-line, with only its adjacent piping for support, as a rule, most federally funded solar thermal projects will utilize 1 hp or greater, circulators. Pumps of that size should be supported independently of the attached piping. **Second Review:** Should be covered by industry standards and building regulations	**First Review:** **Second Review:** Should specify maximum size of pumps that are allowed to be supported by piping. Pump installation requirements should follow manufacturers installation recommendations.
	4	**First Review:** Delete " Pumps shall have stainless steel impellers and casings of bronze" Add "pumps shall have impellers and volutes constructed of materials suitable for the collection fluid."	**First Review:** Agree.
2.7.3 Pipe Insulation	1	**First Review:** Why must insulation conform to the need for 15 PSIG steam? This precludes the use of low-cost high R insulation's on lines at low temperatures with no danger of stagnation temperatures, such as DHW lines, and most of the collector lines.	**First Review:** **Second Review:** Agree. Insulation requirement should meet the application being considered. Pipe insulation guidelines are outlined in the Uniform Solar Energy Code.
2.7.4 Expansion Tank	1	**First Review:** This specification should be relaxed to a working pressure of 100 PSI and max operating temp of 200 degrees for small systems (up to 150 square feet) and 75 PSI relief valve. **Second Review:** Not recommended to relax spec, may even want to raise to 150 psi.	**First Review:** **Second Review:** Disagree. Not warranted to relax pressure requirements. Need to consider stagnation conditions. Spec for large systems (1000-3000 ft^2).

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
2.7.4 Expansion Tank (continued)	2	**First Review:** Why do you need a bladder type expansion tank? It is usually a good choice, but not always, especially for larger systems.	**First Review:** Agree.
2.7.5 Heat Transfer Fluids	1	**First Review:** Section only assumes closed loop glycol systems.	**First Review:** We agree. The specification should allow other types of systems.
	2	**First Review:** Uninhibited propylene glycol becomes corrosive in solar collector surface. Inhibited propylene glycol (Dowfrost) is USDA approved for freezing food products by direct immersion. Ethylene glycol is a legitimate HTF if double wall protection is provided. The percentage glycol should be based on local conditions.	**First Review:** We recommend that the COE require inhibited ethylene glycol except where a potential for cross contamination exists. When such a potential exists, use inhibited propylene glycol and a vented double wall heat exchanger. **Second Review:** Based on discussions with Larry Lister, uninhibited required because the corrosion inhibitors contained in inhibited glycol needs frequent replacement.
2.8.1 Differential Temperature Control Equipment	1	**First Review:** ..of 3 to 5 degrees F, **incorporate a high temperature adjustable limit cut off,** and shall include...Reason: This control allows for control of solar preheat and (suggested) summer bypass modes.	**First Review:** Agree.
2.8.2 Thermistor Temperature Sensors	1	**First Review:** ...immersion wells, **(delete "or")** water tight threaded fittings, **or access to a section of collector header or absorber plate** shall be...Reason: Manufacturers commonly supply pipe-mounted, strap-on sensors which are tried and proven for both differential and freeze detection purposes.	**First Review:** We recommend the COE revise the specification to allow strap-on sensors and prohibit immersion sensors without thermowells.
	2	**First Review:** Thermistors shall be hermetically sealed glass type". This is an unusual spec, which does not fit any standard sensors available. Immersion type sensors are normally sealed in brass. Suggest allowing for a strap-on sensor for the collector (cannot provide a well on a collector header for a sensor)	**First Review:** Agree.
2.8.3 Sensor and Control Wiring	1	**First Review:** 18 AWG is acceptable (wet or damp locations) for lengths not exceeding 100 feet if installed in an approved conduit.	**First Review:** Agree.
	2	**First Review:** Code does not require low-voltage control wiring to be in conduit.	**First Review:** Agree.
2.8.4 Flowmeter	1	**First Review:** Flowmeters other than the specified dial are commercially available, cost less, and yield longer design life. Other types of meters should be considered.	**First Review:** We recommend the COE omit this paragraph . . . . **Second Review:** . . . or not specify venturi meters.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
2.8.4 Flowmeter (continued)	2	**First Review:** A venturi is an expensive flow meter. Why is such accuracy required? These are not R&D projects. It would be much more effective to put instrumentation money into a low cost Btu metering system that would record performance.	**First Review:** See above comment.
	3	**First Review:** Suggest a minimum size system before requiring such a flowmeter.	**First Review:** See above comment.
2.8.5 Sight Glass Indicator	1	**First Review:** Same comment as 2.8.4 (That is, minimum size).	**First Review:** See above comment.
3.1.1.1 Collector Array	1	**First Review:** 18" above ground or roof for collector mounting is excessive and just adds to the cost.	**First Review:** Disagree, what about re-roofing requirements? **Second Review:** 18 inch is probably required for roof mount systems, may be excessive for ground mount.
	2	**First Review:** ...on the structural drawings. **These drawings to indicate the acceptable water proofing techniques...**Reason: See 1.2,(5)	**First Review:** We agree.
3.1.1.2 Piping	1	**First Review:** Reverse return piping is not always the best way to avoid flow maldistribution. Also, it is redundant to also call for flow balancing valves.	**First Review:** Collector array piping shall be as shown on the drawings.
3.1.1.3 Array Support	1	**First Review:** See 2.5.3 above. That is, a number of manufacturers test to wind load.	**First Review:** We agree with the specification, as written, except its requirement that support structures be aluminum.
3.1.2 Storage Sub-system	1	**First Review:** Suggest rephrasing to allow for long dip tubes to bottom in lieu of fittings near bottom.	**First Review:** Agree.
3.1.3.1 Flow Rates	1	**First Review:** Suggest not requiring the storage loop flowrate to be 1.25 times the collector loop flowrate.	**First Review:** Flow rates shall be as shown on the drawings.
3.1.3.4 Piping, Valves, and Accessories	1	**First Review:** ...installed in the system. **Manual** air vents shall be...	**First Review:** See our comment to Paragraph 2.2.11 Air Vents.
3.1.3.2 Pumps	1	**First Review:** This spec may not apply to all system sizes, and particularly not to packaged systems, where pumps may be mounted onto heat exchangers or welded frames.	**First Review:** We agree with the specification, as written.

Section 13600 Solar Water Heating Equipment Review

Specification Paragraph	Comment No.	Industry Comment	STDAC Comment
3.1.3.5 Pipe Expansion	1	**First Review:** Expansion joints are legitimate piping options that should not suffer a blanket exclusion. Expansion joints can be installed without being cold-sprung. The temperature changes are not large. **Second Review:** One reviewer disagrees, believes expansion joints have not proven durable in solar installations.	**First Review:** We disagree. **Second Review:** Expansion loops are the safest way to design for pipe expansion. STDAC agrees with spec.
	2	**First Review:** One of the most important stress point occurs where the feeder and return lines attach to the collector array. Too tight a turn there may not allow the absorber sufficient room to float and may unduly stress header/riser connections. This problem could be addressed in the spec.	
3.1.3.6 Valves	1	**First Review:** "...or above. **Globe (rather than gate)** or ball valves shall be..." "...a union immediately adjacent. **Ball** valves should be..." In applications where they are not regularly exercised, foreign matter tends to accumulate in the seat of gate valves, with the result that they either "freeze" closed, or the gate is not able to fully seat, allowing the valve to leak. Both globe and gate valves are much more reliable in this regard.	**First Review:** Disagree, globe valves cause high pressure drops . . . **Second Review:** . . . and more expensive.
	2	**First Review:** Balancing valves should be reserved for large systems with multiple collector banks where reverse return not practical (either balancing valves or reverse return)	**First Review:** We recommend the COE omit the requirement for a balancing valve at the pump discharge.
3.1.4.1 Differential Temperature Controller	1	**First Review:** Sensors which are made of the same material as collector piping (copper) may be mechanically strapped (hose clamp) to the collector loop return outlet piping if within 2 feet of the outlet header.	**First Review:** We agree.
	2	**First Review:** As stated previously, suggest allowing an insulated strap-on collector sensor, which can be mounted on a header at the outlet. Penetrating a collector header to insert a sensor well is not recommended by the collector manufacturers. Although at times practiced, attachment of the sensor directly to the absorber inside the collector is not recommended because of the high potential stagnation temperatures, which cause sensors to fail and drift.	**First Review:** We agree.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
3.1.4.2 Sequence of Operation	1	**First Review:** ...below 5 [ ] degrees F. In an open loop system, the controller must be equipped with a recirculation freeze or other freeze protection capability. All controllers will be equipped with a high temperature cut-off capability. Open systems will require some type of freeze protection.	**First Review:** Agree. **Second Review:** However, open system not considered by spec.
3.2.2.1 Hydrostatic Test	1	**First Review:** Suggest adding "beware of risk of freezing while testing when ambient temperatures may drop below 40 degrees. **Second Review:** Because of isolation of expansion tank and pressure relief valves, test during hours of darkness (beware of freezing).	**First Review:** Agree.
3.2.2.2 Cleaning of Piping	1	**First Review:** Typically it is desirable to heat wash fluid in the collector, and therefore it is not necessary to cover the collectors. **Second Review:** One reviewer disagrees, risky because pressure relief valves are isolated and stagnation could cause bursting to occur.	**First Review:** Agree. **Second Review:** However, would not want to allow system to stagnate.
	2	**First Review:** "The solution shall be circulated..." What solution? How is it made?	**First Review:** We recommend the COE clarify this paragraph.
	3	**First Review:** ...with clean **deionized** water prior to...Reason: D.I. water is both a powerful cleaner and an environmentally friendly "detergent" for cleaning the flux residual and miscellaneous contaminants from systems piping. **Second Review:** If contractor wants to use DI water then let him.	**First Review:** We disagree -- we question the cost of using DI water.
3.2.4.4 System Filling	1	**First Review:** See 2.7.5 above. That is, section only assumes a closed loop glycol system.	**First Review:** Agree. **Second Review:** Spec only for closed loop systems.
	2	**First Review:** It is impossible to completely drain the system of water. Hence, it is desirable to pump in the desired volume of glycol and then makeup the rest with water.	**First Review:** Agree.
	3	**First Review:** Suggest adding (1) fill system while the collectors are cold or covered (2) fill pressure approximately 30 PSI (3) air vents shall be closed after venting	**First Review:** We agree with items 1 and 3, but feel that item 2 depends on the application.

Section 13600 Solar Water Heating Equipment Review			
Specification Paragraph	**Comment No.**	**Industry Comment**	**STDAC Comment**
3.2.4.6 Control Logic	1	**First Review:** By **utilizing the digital readout on the face of the differential thermostat,** contractor shall demonstrate...(delete "by substituting...sensors.") See "2.8.1,#21	**First Review:** We disagree. We feel the contractor should demonstrate correct operation of the system by simulating temperatures either by substituting resistors or changing the temperature of the medium.
3.3 Field Training	1	**First Review:** Who is responsible for the training? If the contractor, will this become an element of the bid spec and quotation?	**First Review:** The installing contractor.

APPENDIX E

Generic Solar Hot Water System Specification

This page left intentionally blank.

SYSTEM DESCRIPTION

[*This section is application specific.* ***Define the application, load, setpoints, and conventional system. Define the system and list the major components necessary.]***

STATEMENT OF WORK

The contractor shall design, build and place into operation, a solar domestic hot water system that will displace at least [*application specific %*] of the annual hot water energy load for the [*application*]. All work and components shall be per local code.

SOLAR SYSTEM EQUIPMENT

Furnish materials and equipment that are the standard products of a manufacturer regularly engaged in the manufacture of such products and which essentially duplicates items that have been in satisfactory use for at least 5 years prior to bid opening.

(1) Solar Array

The following technologies will be considered for this project. Any collector proposed must be commercially available for at least the previous five (5) years.

(a) Flat Plate Collector and Support Structure

Required:

- Current SRCC certification
- Low iron, tempered glass glazing

- Absorber to have selective surface
- Rack assembly to be certified for [*application specific* mph] wind load
- Vent slots protected from weather and clogging

Preferred:

- All copper absorber
- Blackchrome selective surface
- One piece of glass, fully supported on all four sides
- EPDM rubber gasket
- One-half inch o.d. riser tubes

(b) Parabolic Trough

- Submit a report, prepared by an independent testing laboratiory, which documents the performance of the trough and identifies the testing procedure used.
- Reflective surface will have a life of 10 years or greater.
- Reflectivity of reflective surface to be greater than 90%.
- Absorptivity of reciever tube to be greater than 90%.

Preferred:

- Receiver tupe enclosed in a glass jacket with a transmittance of greater than 90%.

(c) Other Solar Technologies

Other solar technologies will be considered:

- Submit a report, prepared by an independent testing laboratiory, which documents the performance of the trough and identifies the testing procedure used.
- The technology has been commercially available for at least 5 years.

- Submit a list of at least three installations of this technolgy. Collectors most have been in service for at least 3 years. Supply name of contact at installation.

(2) Thermal Energy Storage Tank

- Cylindrical tank, insulation with an R value of not less than 12 hr-ft^2-°F/btu.
- The insulation shall be protected by a PVC, aluminum or steel jacket.
- That tank shall be designed, built, and stamped per ASME B&PV Code, Section VIII.
- The tank shall be lined for potable water service.
- Tank is to be installed near the conventional water heater with connecting piping being kept as short as possible.

(3) Heat Exchanger

- Heat exchanger(s) shall be shell & tube, tube-in-tank, or plate & frame type
- Will be stamped with ASME "U" symbol.
- Will be registered with the National Board of Boiler and Pressure Vessel Inspectors.
- To be installed near the storage vessel with connecting piping being kept short.

(4) Piping

- All solar loop piping shall be Type L or K copper.
- Piping shall be sized to limit flow velocity to less than 6 ft/s.
- Dielectric insulators at joints between dissimilar materials shall be used.

If a drainback system:

  - Both supply and return piping must be sloped so all collector fluid will gravity drain to the drainback tank whenever the solar loop pump is deactivated.
  - Final downcomers to the drainback tank must extend below tank operating water levels to reduce water splashing and aeration.

- A vent pipe from the top of the drainback tank to the final downcomer is required. This vent pipe shall be connected to the highest point of the final downcomer within the building.
- Piping shall be a reverse return piping arrangement.

(5) Balance of System

Provide:

- Valves for isolating solar system from conventional water heating system such that conventional system can remain in service when solar system is isolated for repair.
- Valves for isolating each bank of collectors.
- Circulation pump(s), relief valve, expansion tank, etc... as necessary.

(6) Heat Transfer Fluid (closed loop collector system)

- The heat transfer fluid shall be a [*application specific%*] solution of inhibited propylene glycol and water.
- Design of the collector loop shall incorporate provisions for obtaining samples of collector fluid, addition of makeup, draining, flushing, refilling, air venting and repressurization.

(7) Instrumentation & Controls

Provide:

- Temperature indicators at inlet and outlet of all components that generate, transfer, or store thermal energy. Supply temperature indicators with wells and bronze sockets.
- Pressure gage for each pump. Gage piping shall be such that both pump suction and pump discharge pressures can be read by each gage.
- An automatic control system to start and stop the pump(s).

(8) Energy delivery performance monitoring

- The installed system is to include a subsystem for measuring and totalizing solar-delivered BTU's to the load.

(9) Balancing & Testing

- New water lines shall be hydrostatically tested to 1.5 times the normal working pressure of the line. Test duration shall be not less than two hours. During the test, there shall be no lose of pressure. Hydrostatic testing involving solar collectors will be done during early morning hours prior to sunrise, or, with collectors covered.
- Flow rate through the collectors shall be per manufacturers recommendations.
- System piping shall be flushed with clean, fresh water prior to concealment of any individual section and prior to final operating test. Prior to flushing piping, relief valves shall be isolated or removed. The solution shall be circulated through the section to be cleaned at the design flow rate for a minimum of 2 hours.
- Contractor shall demonstrate that controls function per design in all modes of operation.

DOCUMENTATION AND TRAINING

(1) System Cost

- The contractor shall document and supply the solar system installed cost, including materials, equipment and labor.

(2) Manuals

- The contractor will provide a system operation and maintenance manuals. The manual will contain:
  - System drawings and schematics, including control logic diagram (or sequence of operations) sufficient for use in O&M and trouble shooting.
  - A complete parts list including manufacturer, part number and description for each component.
  - Maintenance requirements and recommended schedule.

(3) TRAINING

- Four hours of on-site training, including trouble-shooting procedures, for the maintenance staff having responsibility for operating and maintaining the solar system.

WARRANTIES

- The contractor shall warrant that the work shall be performed by persons qualified in their respective trades and shall warrant the performance of materials, equipment, and workmanship for a period of one year from acceptance of the system.

CODES

- The system and alterations to any existing system shall be in compliance with UL and NEC standards as well as all applicable codes and regulations.

EXPERIENCE

- The contractor will have at least five years experience installing solar systems.

PROPOSAL REQUIREMENTS

1. Qualifications and experience to include as a minimum:

- Number of years in this type of business.
- Experience of individuals who will be assigned to the project.
- Three references for whom the Offeror has provided this type of service to include address and telephone number whom [engineering?] may contact to verify quality of service provided.
- List of relevant licenses held by the firm and/or individuals to be assigned to the project.

2. Provide written material which includes:

- A description of the proposed system, detailing all sub-components including piping, tank, insulation, heat exchanger and control scheme. Provide the names of the major component manufacturers .
- Design flow rates, collector array size, orientation and tilt angle, number of collectors to be grouped per bank and collector loop fluid volume. Space collectors arranged in multiple rows so that no shading from other collectors is evident between 1000 hours and 1400 hours solar time on December 21. Indicate minimum spacing between rows.
- Expected annual and monthly energy performance which includes annual and monthly energy load met by the solar and details of the sizing of the solar array.
- Describe how the solar system will minimize thermal losses during non-operational hours.

- Describe how the solar system will mitigate against possible freeze damage.
- Describe how the solar system will mitigate against possible over heating of the solar loop.
- Provide a schematic drawing or system diagram of the proposed solar DHW system.

3. System Price

- Provide a price proposal showing separate prices for designing the system, all necessary installation labor, and all equipment and material costs.
- Provide O&M costs with cost details of expected maintenance requirements to achieve full system life.
- Provide a price for a 1-year maintenance agreement. Describe in detail all preventative maintenance included in the agreement.